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A LIMIT CYCLING SPEED CONTROL SYSTEM

by

Hasan Kocaoglu

United States
Naval Postgraduate School

THESIS

A LIMIT CYCLING SPEED
CONTROL SYSTEM

by

Hasan Kocaoglu

December 1970

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A Limit Cycling Speed
Control System

by

Hasan Kocaoglu
Lieutenant (junior grade), Turkish Navy
B.S., Naval Postgraduate School, 1970

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL
December 1970

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ABSTRACT

The concept of a limit cycling control in power supplies and speed control has advanced the application of these broad areas. ON-OFF switching of a thyristor provides a simple and economical method of control and regulation. This switching of the thyristor causes the system to limit cycle.

Basic analysis and design of speed control was performed. A describing function was developed to model the power-supply and rectifier bridge. Then it was used to predict the frequency and amplitude of the limit-cycle.

A digital computer program was used to simulate the system response and to construct the describing function curves. To verify the describing function validity, the limit cycle predictions were compared with the simulated results.

Fourier analyses were performed to determine the ripple instability and subharmonic effect of the system output.

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The author wishes to express his appreciation to Dr. G. J. Thaler for the invaluable aid and counsel which he has offered during the preparation of this thesis.

I. INTRODUCTION

Limit cycling control systems have enjoyed considerable popularity both in practice and in the literature. The practical reasons for which limit cycling systems have been developed are numerous, not the least important of which is the simplicity of an on-off power element. The first step toward such a theory was actually taken by Lozier (Ref. 6) at which time certain qualitative remarks were made. Thereafter it received little attention in the English literature. The paper by Li and Vander Velde (Ref. 7) represented an independent rediscovery of some fundamental principles regarding limit cycling control systems. Work of a similar nature has also recently been published in the U.S.S.R.

In this discussion stress is placed on considerations of the limit-cycling system as a control system and its signal transmission properties are derived as well as the loop limit cycle.

The discussion is limited to negative feedback configurations with a nonlinearity in the forward loop, such as shown in Figure 1.1. Here N stands for the nonlinearity, and G(s) for the loop linear elements. It is assumed that this is a limit-cycling system. That is, in the absence of an input, the system sustains a nearly sinusoidal undamped oscillation at its output. If, as is commonly the case, the function of this system is to reproduce the input signal at a higher power level at its output, then its response to a

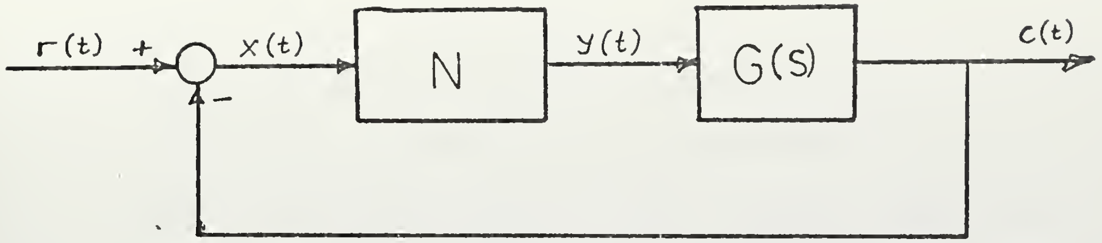


FIGURE 1.1: Simple limit cycling control system.

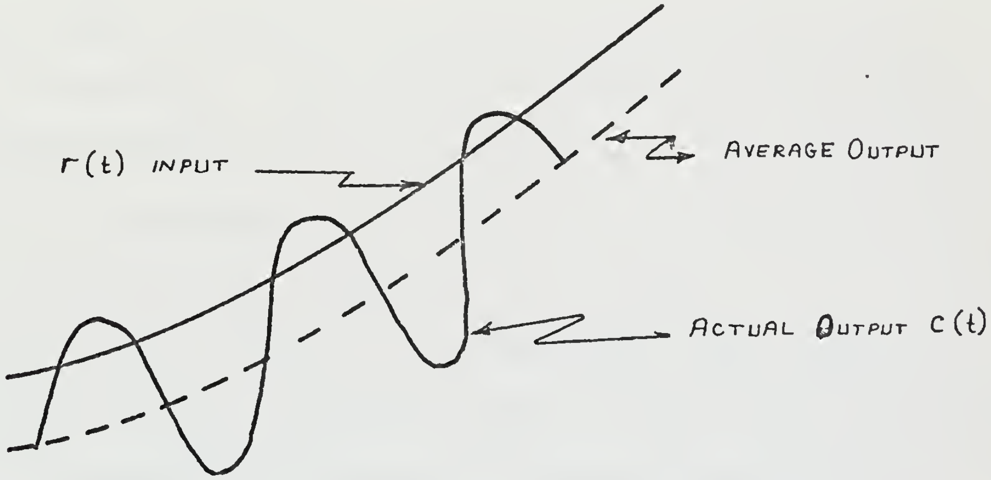


FIGURE 1.2: Typical input and its corresponding output.

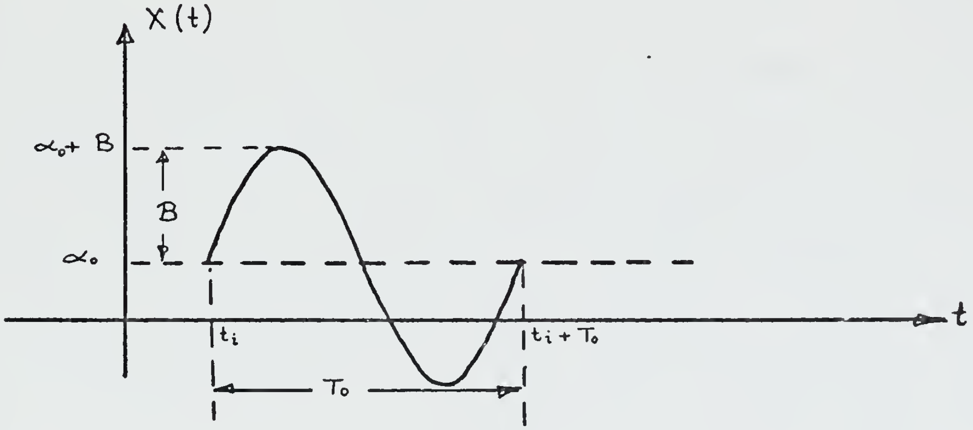


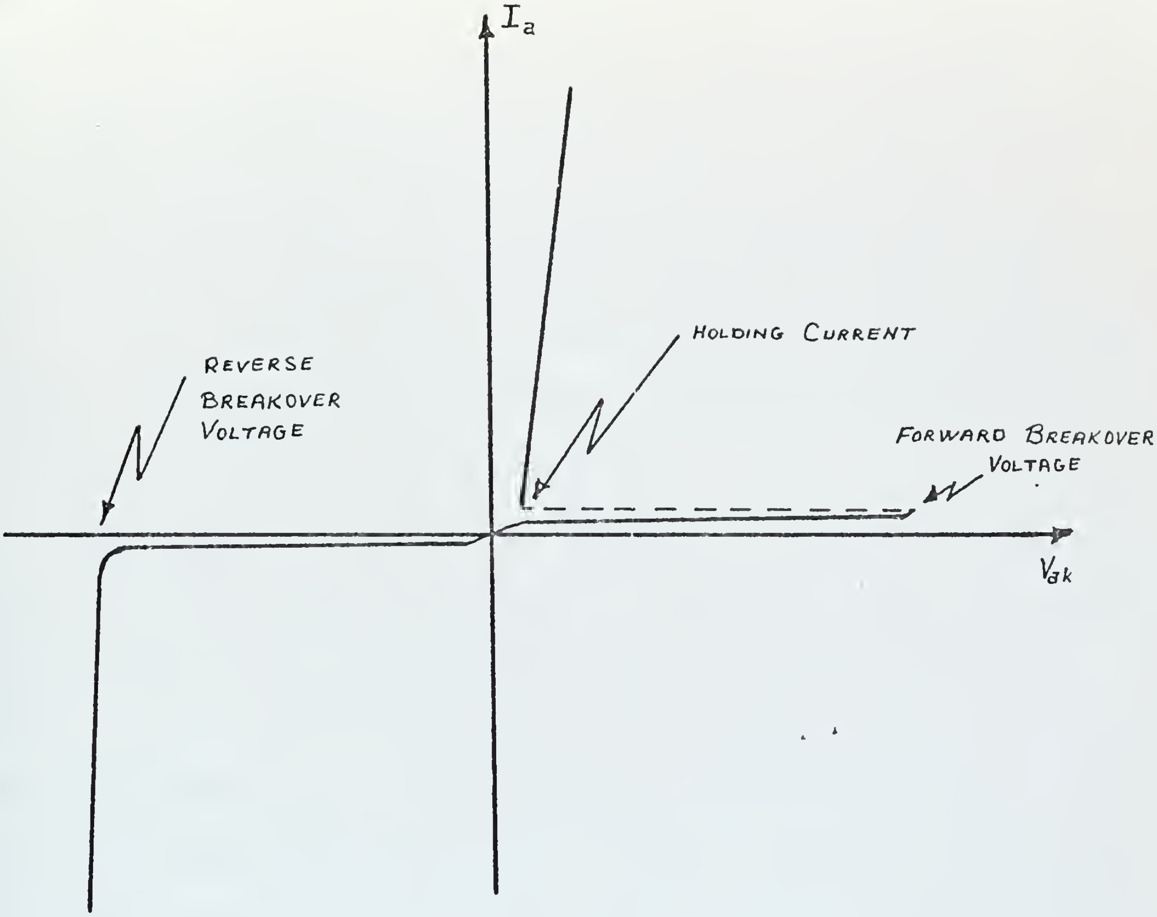
FIGURE 1.3: Model of x(t) over any limit cycle.

slow input signal might look as shown in Figure 1.2. For a well-designed control system the output follows the input on the average, within some dynamic following error. Over any period of the limit cycle, T_o, an approximate model of this error signal is shown in Figure 1.3. In this model the sinusoid of amplitude B is associated with the limit cycle, and the D-C bias of amplitude α with the input forced following error.

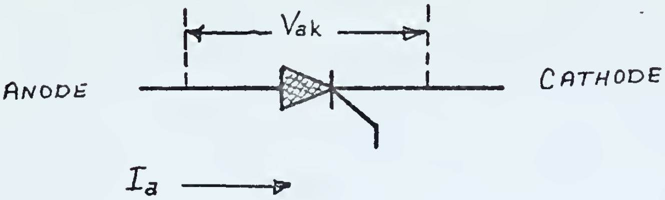
In this study a system which has properties mentioned above will be examined. The specific system to be examined is an armature voltage controlled D-C motor. Its armature is supplied with a poly-phase, thyristor, A-C to D-C rectifier and its field excited by a separate D-C source.

The goal in this study is to investigate the control of speed of this D-C motor, operating under forced limit cycling conditions. A mathematical model is proposed and then analyzed using frequency response techniques.

The thyristor, which is used in the rectifier bridge is a four layer, three terminal solid-state device. Functionally it is equivalent to its gas tube counterpart, a thyratron. The characteristics and circuit symbol of the thyristor are shown in Figure 1.4. In the forward direction the device has two stable modes of operation, one of high impedance, of similar amount to that in the reverse direction and the other, of very low impedance. In general the forward break-over voltage is inversely proportional to the gate current. This indicates that the device could be controlled by controlling



a - Transfer characteristic



b - Circuit symbol

FIGURE 1.4: Thyristor transfer characteristics.

the level of gate current. The control of the forward breakover voltage provides the interval of the forward conduction and thus the amount of power per cycle may be regulated. In this paper it is assumed that the entire rectifier bridge is controlled as a unit rather than by individual device for each thyristor. The gates of all thyristors in the polyphase bridge are connected in parallel and a single firing signal is provided to all devices. A simplified circuit diagram is contained in Figure 1.5.

Conceptually the system operates as follows: assume that the output speed is below the reference speed. The rectifier bridge is then supplied with an ON signal, and the bridge output to the armature of the D-C motor is a three-phase, full-wave rectified voltage. The filter action of the motor alternates the harmonics of this voltage and provides a relatively smooth speed at the output. When the speed rises above the reference level the bridge is supplied with an OFF signal. There is a time delay before the bridge turns off, because the shut off conditions for all thyristors must be met. The time delay is approximately of the order of ¼ cycle of the supply frequency. In the OFF state the input voltage to the armature of the D-C motor is zero with reverse current essentially blocked. The bridge will remain in the OFF state until the output speed falls below the reference, whereupon the cycle will repeat itself. This limit cycling of the system is the particular area to be considered here.

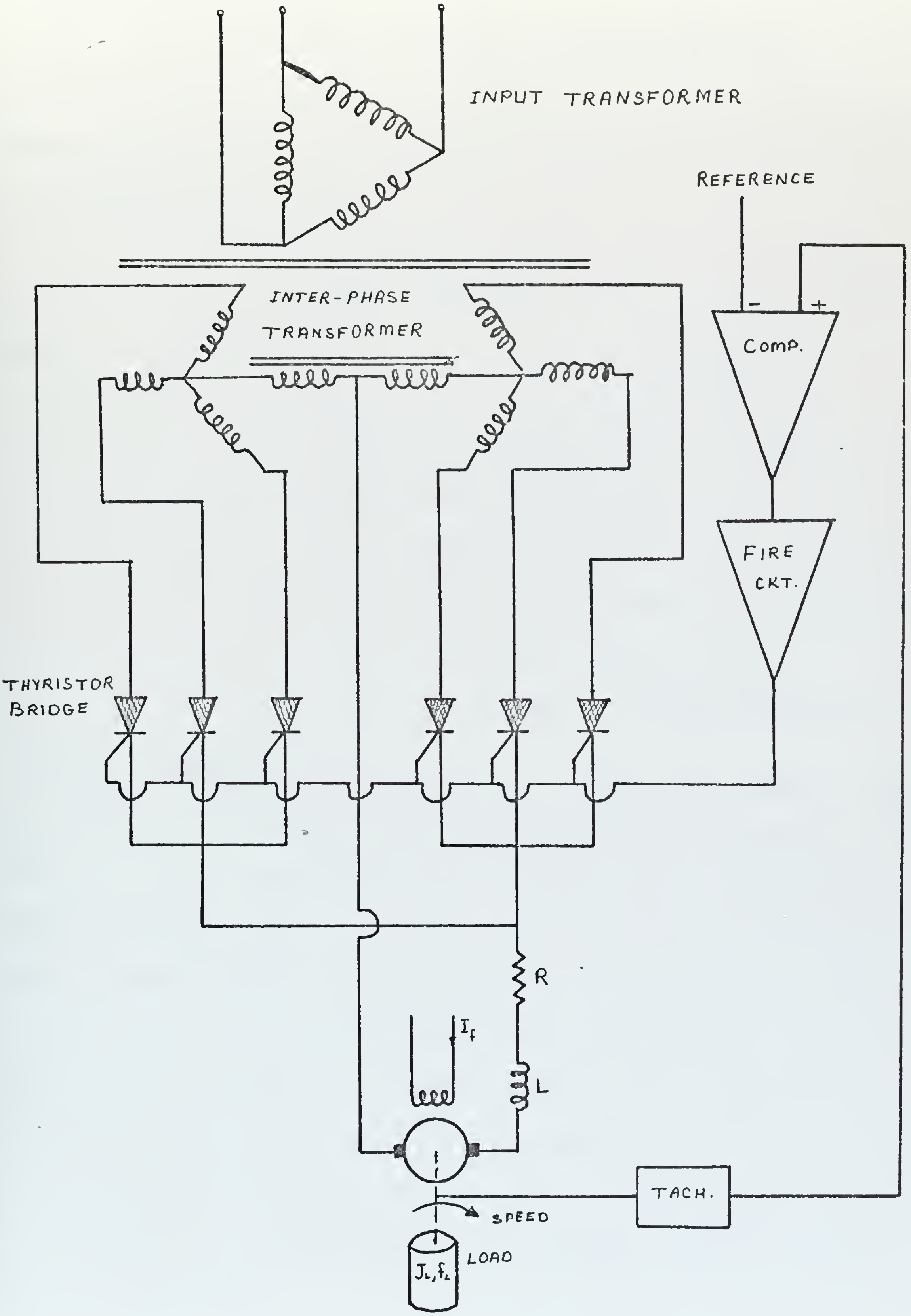


FIGURE 1.5: Simplified circuit diagram of the system.

II. BASIC ANALYSIS AND DESIGN OF SPEED CONTROL

D-C motors with shunt excitation are particularly applicable for speed control systems. The speed of this motor can be expressed by

$$\omega_m = \frac{V_a - i_a R}{C_1 \Phi} \tag{2-1}$$

where,

ω_m = Speed of motor
V_a = Armature voltage
i_a = Armature current
R = Resistance of armature circuit
Φ = Operating magnetic flux
C_1 = Coefficient of proportionality

It is apparent from equation 2-1, that the speed of such motors can be controlled either by varying the armature voltage, V_a, or the operating flux, Φ, that is, by varying the field-excitation current of the motor. However, the advantage of speed control characteristics of a D-C motor cannot be fully utilized unless an adjustable D-C voltage can be applied to the armature. In order to take full advantage of a D-C motor characteristics, it is necessary to provide an adjustable output voltage converter which would convert the A-C line voltage into an adjustable D-C voltage, which can be applied to the motor.

The very popular rotating converter consisting of an A-C motor driving a D-C generator, and known as the "WARD LEONARD" system, is one of the most widely used adjustable voltage supplies.

The rectifier converter, combined with complete electronic control and regulating system is perhaps the most practical unit available. Its prime advantage over the rotating type converters is that only one rotating machine is used instead of three. In addition, the compactness of the electronic system, the flexibility for adaptation to various conditions, accuracy, and sensitivity are improved.

The particular interest here is to control the speed of a D-C motor by controlling the conduction angle of the thyristors, which are used as an A-C to D-C converter to supply the armature of the motor as shown in Figure 1.5. In this configuration a feedback control system was employed to achieve the desired performance.

The system in its simplest block-diagram form is illustrated in Figure 2.1. In order to permit analysis, the system components are lumped and partitioned as illustrated in Figure 2.2. In this figure, block "G_2" represents the motor and load. It is assumed that they are entirely linear. Block "G_1" is included to take into account any gain that may be associated with the comparator, firing circuit, and compensation network which may be added to the system. Again, this block is assumed to be linear. The source and rectifier bridge are represented as block "N" which is assumed to have a periodic input and output for development of basic describing

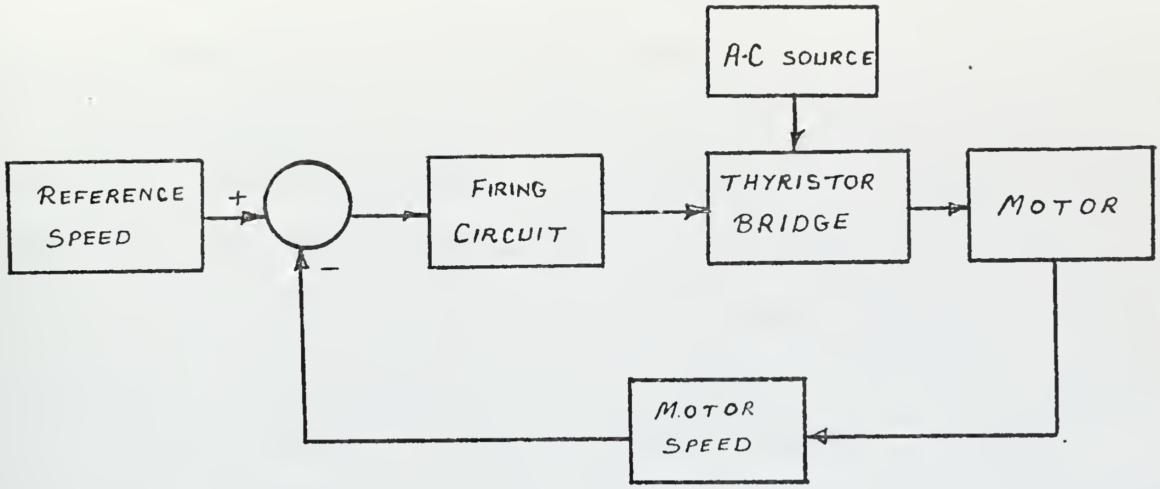


FIGURE 2.1: Block diagram for regulated speed control.

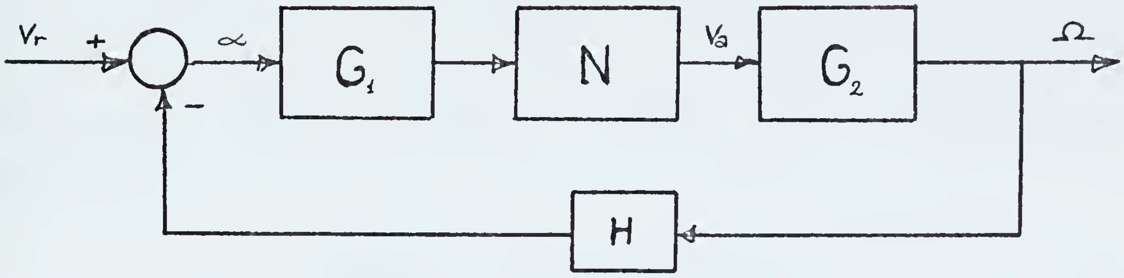


FIGURE 2.2: Simplified block diagram.

function (which will be mentioned later in this study). The general nature of this block is nonlinear. Block "H" represents a conversion factor of the speed to the voltage. It can be considered as a feedback gain.

The principle of operation can be described as follows: the speed setting voltage, V_r, represents the desired motor speed, and the tachometer gives K_t per radian per second, which is directly proportional to the tacho generator speed. Regulation of tachometer voltage is equivalent to the regulation of motor speed. The difference between V_r and the tachometer voltage, $K_t\omega_m$, is an error signal which can be represented as

$$\alpha = V_r - K_t\omega_m \qquad (2-2)$$

This signal shows the deviation of the motor speed from its desired value. The purpose of the automatic speed control is to minimize this error signal and obtain the desired value of the speed. This error signal operates the firing circuit, it controls the motor speed by adjusting the conduction angle of the thyristors in the rectifier bridge, thus altering the average current and voltage value of the armature circuit.

One procedure for analysis of the system is by using the conventional transfer function concept. The system transfer function is

$$\frac{\Omega(s)}{V_r(s)} = \frac{G_1(s)G_2(s)N}{1+G_1(s)G_2(s)H(s)N} \qquad (2-3)$$

The linear portion of the system may be block diagrammed as shown in Figure 2.3.

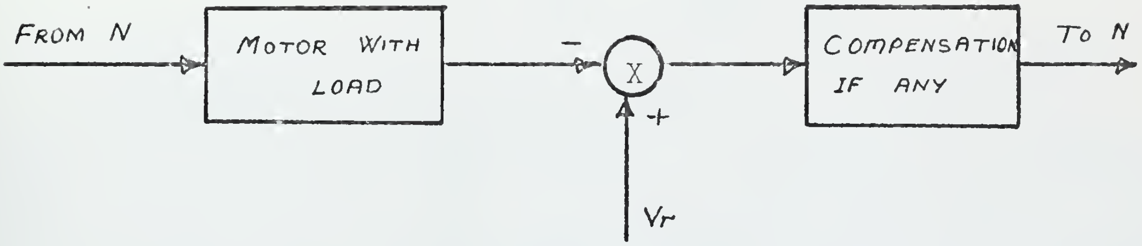


FIGURE 2.3: Block diagram for linear system.

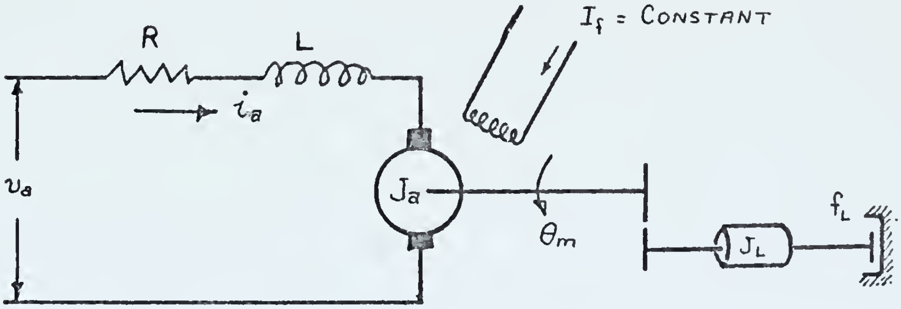


FIGURE 2.4: Motor and load.

The transfer function for the motor and load illustrated in Figure 2.6 is developed as follows. The loop equation for the armature circuit is:

$$V_a = i_a R + L \frac{d\ i_a}{dt} + K_m \omega_m \qquad (2\text{-}4)$$

Torgue-equilibrium equations are

$$T_d = K_t\ i_a \qquad (2\text{-}5)$$

$$T_1 = J\dot{\omega}_m + f\ \ \omega_m \qquad (2\text{-}6)$$

From equations 2-5 and 2-6

$$\dot{\omega}_m = -\frac{f}{J}\ \omega_m + \frac{K_t}{J}\ i_a \qquad (2\text{-}7)$$

and from equation 2-4

$$\dot{i}_a = -\frac{R}{L}\, i_a - \frac{K}{L}\ \omega_m + \frac{1}{L}\ V_a \qquad (2\text{-}8)$$

are obtained.

Choosing state variables as:

$$X_1 = \omega$$

$$X_2 = i_a$$

$$\dot{X}_1 = -\frac{f}{J} X_1 + \frac{K_t}{J} X_2$$

$$\dot{X}_2 = -\frac{K_m}{L} X_1 + \frac{R}{L} X_2 + \frac{1}{L} V_a$$

A signal flow graph of the system is given in Figure 2.5, with 1/s indicating an integration and X_{10} and X_{20} as initial conditions.

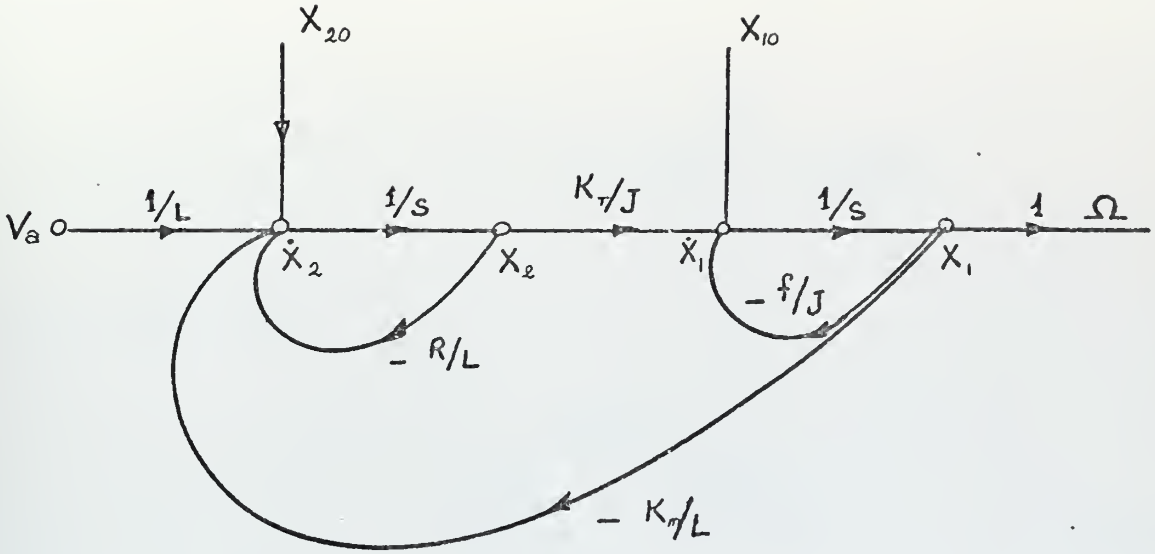


FIGURE 2.5: Signal flow graph for linear system.

Using Mason's gain rule the transfer function in Laplace notation is:

$$G_2(s) = \frac{\Omega}{V_a} = \frac{\frac{K_t}{JL}}{s^2 + \frac{RJ+Lf}{JL} s + \frac{Rf+K_tK_m}{JL}} \tag{2-9}$$

or in Bode form

$$G(s) = \frac{\frac{K_t}{Rf+K_rK_m}}{\frac{JL}{Rf+K_tK_m} s^2 + \frac{RJ+Lf}{Rf+K_tK_m} s + 1} \tag{2-10}$$

Numerical values for the motor parameters and load were selected from Reference 1, Chapter 7, Problem 9.

They are:

Armature resistance	$R = 0.08$ ohm
Armature inductance	$L = 0.008$ Henry
Motor torgue constant	$K_t = 0.95$ Newton-meter/Amp
Motor e.m.f. constant	$K_m = 0.95$ Volt-sec/Rad
Equivalent inertia of motor-load	$J = 1.38$ Kg-m^2
Equivalent viscous friction of motor-load	$f = 0.086 \frac{\text{newton-meter}}{\text{rad/sec}}$
Feedback gain	$K_t = 0.318$ Volt-sec/rad.

By using these values and computer program "LISA 360 A PROGRAM FOR LINEAR SYSTEM ANALYSIS 360 D-16 . 4 . 009", the values of magnitude in "db" and phase of the transfer function were calculated. From these data Bode plot and Nichols plot were obtained for limit cycle investigation. Plots were shown in Figures 2.6 and 2.7.

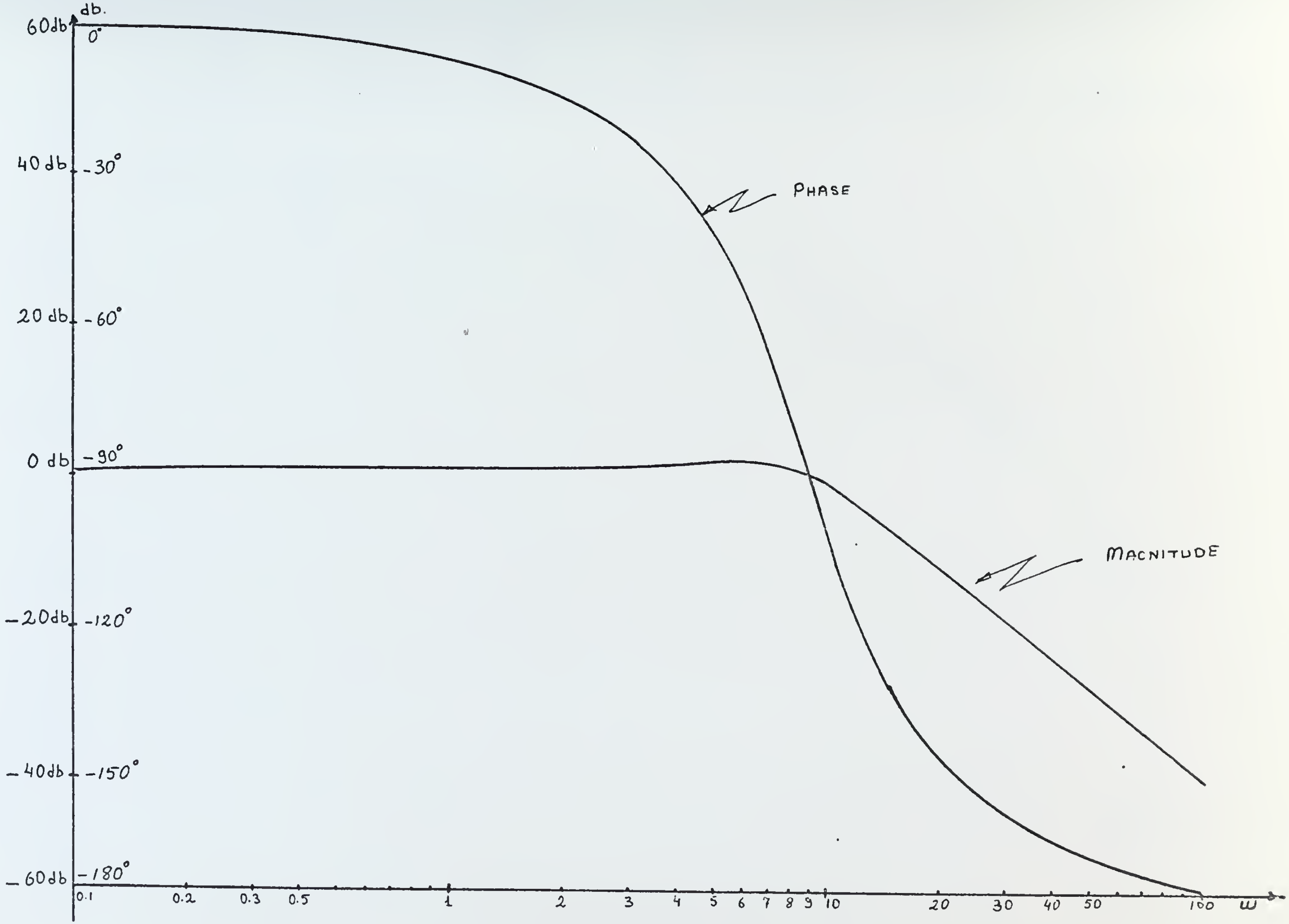


FIGURE 2.6: Bode plot for linear part.

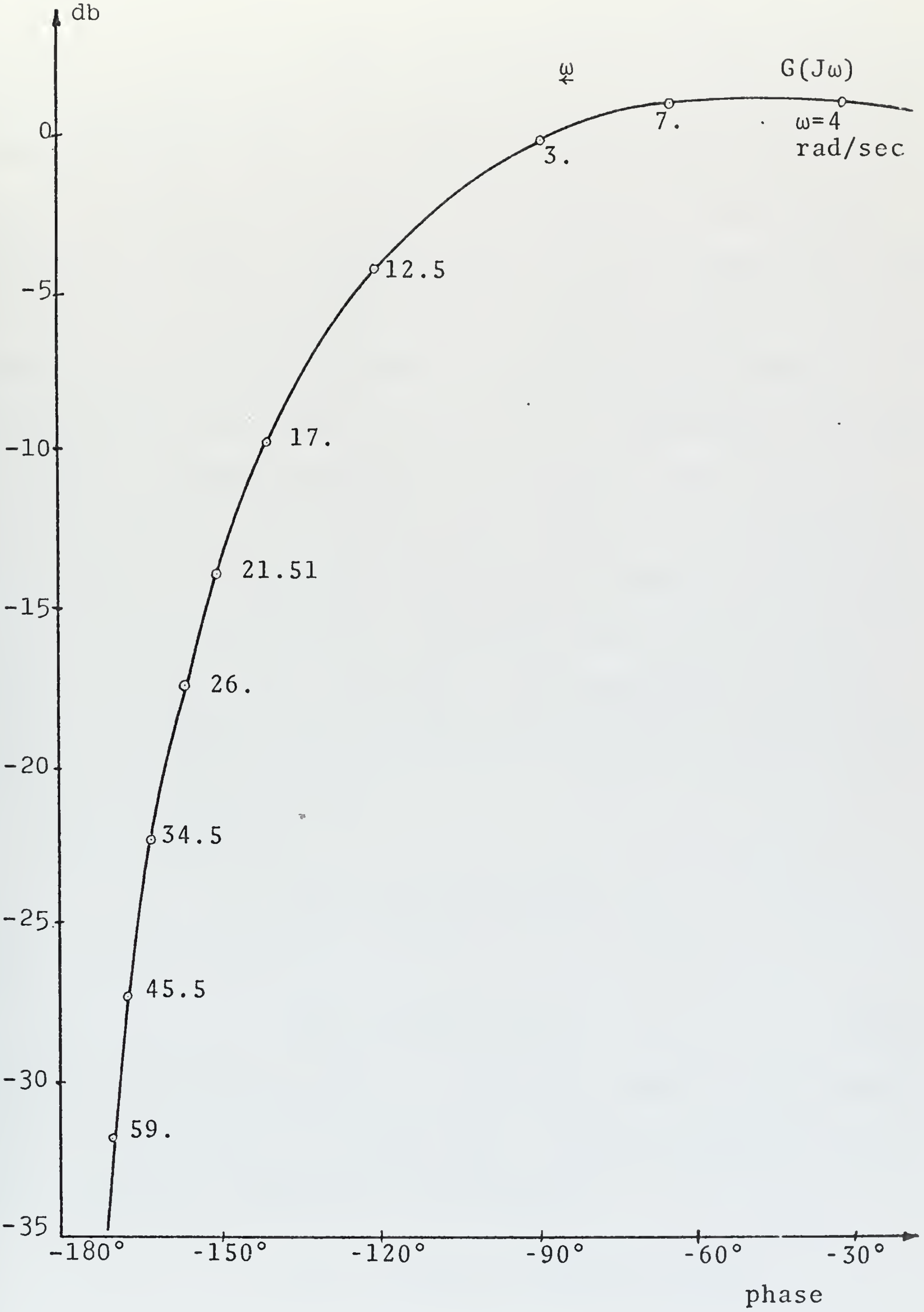


FIGURE 2.7: Nichols chart for linear part.

For a desired value of speed at a specified load, normal practice is to compute the value of firing angle that will produce the desired output, then design the firing circuit to produce a firing angle, α_0, that biases the rectifier to the desired output. Thus, the basic design provides the desired result in open loop operation. The feedback loop is then designed to adjust the system when operating conditions change. If the load is changed this causes a change in speed which causes an error, and the error is amplified and changes the firing angle by an amount β in order to counteract the change in speed. In such a design it is necessary that the firing circuit gain, K_e, be chosen to give the desired steady state speed regulation, then the loop must be checked for stability and for transient response, since the gain is set on the basis of steady state accuracy. It is possible to use an open loop approach which includes the nonlinear characteristic of the rectifier.

From Figure 2.2,

$$\Omega(s) = G_1(s)\ N\ G_2(s)$$

and

$$\Omega(s) = G_2(s)\ V_a(s) \tag{2-11}$$

Assuming armature voltage is a constant, that is the average value of the rectifier output, V_{av}. Using equation 2-3 and motor parameters equation 2-11 becomes

$$\Omega(s) = \frac{86\ V_{av}}{s(s^2 + 10.06s + 82.37)}$$

By applying the final value theorem which is

$$\lim_{t\to\infty} \omega(t) = \lim_{s\to o} s\Omega(s)$$

The steady state value of speed was obtained as below:

$$\omega_{ss} = 1.045V_{av}$$

It is known that the average value of the rectifier output is a function of the error signal, α, and the sensitivity of the firing circuit to the error. If the sensitivity of the firing circuit is improved by using an amplifier and compensation network, better results can be obtained.

As mentioned before, operation of the system depends on existence of a difference between reference speed and measured speed. If the "control gain" of the system is defined as the tachometer output per volt applied to the amplifier when the feedback path is broken.

Control gain

$$G = \frac{K_t \quad \omega_m}{\alpha}$$

Now when the loop is closed

$$\alpha = V_r - K_t\omega_m$$

Then,

$$G = \frac{K_t \ \omega_m}{V_r - K_t\omega_m}$$

$$K_t\omega_m = V_r \frac{G}{1 + G}$$

Thus, the greater the control gain, the closer will be $K_t\omega_m$ to V_r. For high accuracy, high gain is required.

III. PREDICTION OF LIMIT CYCLE CHARACTERISTIC

Procedures for analysis of the linear portion of the system have been previously established by using the transfer function concept. It is desirable to extend these techniques to the analysis of the nonlinear part of the system. Actually, for the nonlinear portion there is generally no exact method for relating the output to the input, in closed form. Most techniques of nonlinear analysis use some sort of approximation, that is, assumed linearity of the system over the desired range of operation to be considered.

The extension of the transfer function representation is more difficult. It requires that the nonlinearity be described by an equation in the frequency domain, and it also requires that, this equation be compatible for use with the transfer functions of the linear components. Practical solution to these requirements is the describing function technique which makes the approximation in the frequency domain.

The basic philosophy of the describing function is that the open-loop control system is excited at its input by a sinusoidal forcing function. The output of the nonlinearity is periodic and can be represented by its Fourier series. This is illustrated in Figure 3.1.

Certain assumptions must be made in the process of this linearization, that the input to the nonlinear component is a pure sine wave, and linear portion of the system following the nonlinearity is a low-pass filter, which is commonly true

in most physical feedback control systems. Thus it is assumed that the only terms of the Fourier series that are passed to the output of the system are the D-C term and the fundamental frequency term. The fundamental frequency term in the Fourier series has the same frequency as the input signal but may differ in amplitude and phase. When the loop is closed this harmonic will propagate itself around the loop and result in a continuous oscillation of the system. Then the describing function may be defined as the ratio of the fundamental term in the Fourier series for the output wave to the input sinusoid considering both magnitude and phase.

In order to get the describing function for a nonlinearity, the output of this nonlinearity is represented by its Fourier series.

$$f(t) = \frac{A_o}{2} + A_1 \mathrm{Cos}\omega t + B_1 \mathrm{Sin}\omega t + --- + A_n \mathrm{Cos}n\omega t + B_n \mathrm{Sin}n\omega t \tag{3-1}$$

The coefficients of the series are given by

$$A_n = \frac{2}{T}\int_o^T f(t)\ \mathrm{Cos}n\ \ \omega t\ dt \tag{3-2a}$$

$$B_n = \frac{2}{T}\int_o^T f(t)\ \mathrm{Sin}n\omega t\ dt \tag{3-2b}$$

The definition of the describing function requires that A_n and B_n for $n \geq 2$ are negligible. Thus the coefficients of interest are A_1 and B_1, and they define the fundamental frequency output as

$$O(t) = |\ A_1{}^2 + B_1{}^2|^{\frac{1}{2}}\ \underline{/\ \tan^{-1}(A_1/B_1)} \tag{3-3}$$

Then the describing function for the system as illustrated in Figure 3.1 is

$$N = \frac{|A_1^2 + B_1^2|^{\frac{1}{2}}}{B} \underline{/\tan^{-1}(A_1/B_1) - \phi} \quad . \tag{3-6}$$

The above criteria will now be applied to the system under consideration.

A mathematical description of the output wave shape of the nonlinear block must first be obtained for derivation of the describing function. After that the Fourier analysis is worked out to get sinusoidal components of it.

Referring to Figure 3.2, the output of the system has a certain constant speed, and a ripple which is superimposed on this constant level. The first harmonic of the ripple is defined as BSinωt, and the difference between the constant level and the reference speed as

$$\alpha_0 = V_R - V_{DC} .$$

The system is presumed to operate as follows:

a) When the constant level of the speed plus the ripple is less than the reference level the rectifier bridge is "ON" between time a to b, and the output of the nonlinear portion of the system is a three-phase, full-wave rectified voltage of mean value A.

b) At time b where the constant speed plus the ripple equals the reference speed, the rectifier bridge receives an "OFF" signal.

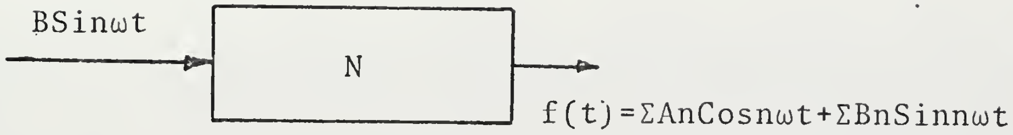


FIGURE 3.1.

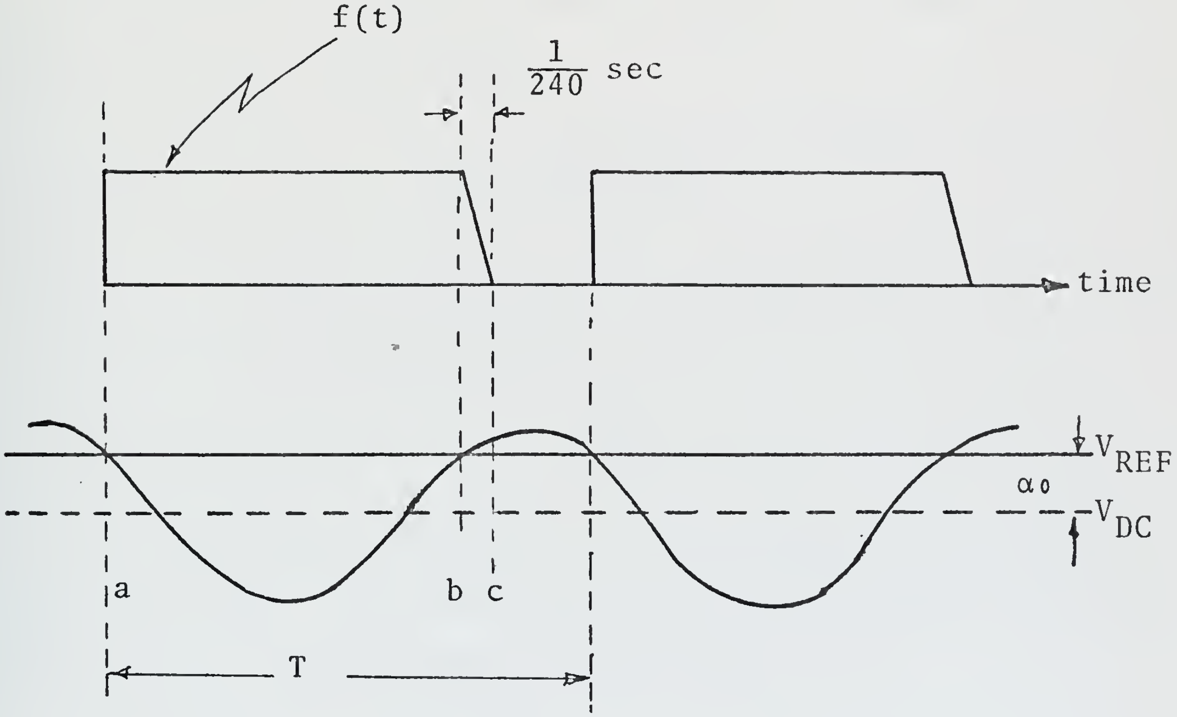


FIGURE 3.2.

c) The rectifier is turned off at time equal to c, a delay of 1/240 second after time b.

d) The rectifier remains off until the output speed again falls below the reference. (Time c to T.) Then the output of the nonlinear block may be summarized as follows:

$$
\begin{aligned}
f(t) &= 0 && 0<t<a \\
&= A && a<t<b \\
&= A\,\frac{c-t}{c-b} && b<t<c \\
&= 0 && c<t<T
\end{aligned}
$$

The times a, b, and c can be defined in terms of the first harmonic of the ripple.

$$b = \frac{\mathrm{Sin}^{-1}\,\frac{\alpha}{B}}{\omega}$$

$$a = \frac{\pi}{\omega} - b$$

$$c = b + \frac{1}{240}$$

To find the coefficients of the Fourier series equations 3-2a,b are used. The integration must be evaluated over one full cycle of the disturbance frequency, T.

Procedure is as follows:

$$A_n = \frac{2}{T}\int_o^T f(t)\ \mathrm{Cos}\,n\omega t\ dt$$

$$\frac{c-t}{c-b} = 240b + 1 - 240\ t$$

Then,

$$A_1 = \frac{2A}{T}\left|\int_a^c \mathrm{Cos}\,\omega t\ dt + 240b\int_b^c \mathrm{Cos}\,\omega t\ dt - 240\int_b^c t\ \mathrm{Cos}\,\omega t\ dt\right|$$

Integrating and substituting the limits:

$$A_1 = \frac{2A}{T\omega}\left|\begin{array}{l}\mathrm{Sin}\,\omega C - \mathrm{Sin}\,\omega a + 240b\,\mathrm{Sin}\,\omega c - 240b\,\mathrm{Sin}\,\omega b - \frac{240}{\omega}\,\mathrm{Cos}\,\omega c \\ -240c\,\mathrm{Sin}\,\omega c + \frac{240}{\omega}\,\mathrm{Cos}\,\omega b + 240b\,\mathrm{Sin}\,\omega b\end{array}\right|$$

Cancelling terms, the above reduces to:

$$A_1 = \frac{2A}{T\omega}\left| - \mathrm{Sin}\,\omega b + \frac{240}{\omega}(\mathrm{Cos}\,\omega b - \mathrm{Cos}\,\omega c)\right|$$

Using trigonomatric identities and substituting the following values,

$$\omega = \frac{T}{2\pi}\ ,\quad \mathrm{Sin}\,\omega b = \frac{\alpha}{B}\ \text{and}\ \mathrm{Cos}\,\omega b = \frac{\sqrt{B^2 - \alpha^2}}{B}$$

The final form of the A_1 term is found as equation 3-5.

$$A_1 = \frac{A}{\pi B}\left|-\alpha + \frac{240}{\omega}\left(\sqrt{B^2-\alpha^2}\left(1-\mathrm{Cos}\,\frac{\omega}{240}\right) + \alpha\,\mathrm{Sin}\,\frac{\omega}{240}\right)\right| \qquad (3\text{-}5)$$

Proceeding in a like manner B_1 is found as equation 3-6.

$$B_1 = \frac{A}{\pi B}\left| - \sqrt{B^2 - \alpha^2} + \frac{240}{\omega}\left(\alpha\left(1-\mathrm{Cos}\,\frac{\omega}{240}\right) - \sqrt{B^2 - \alpha^2}\ \mathrm{Sin}\,\frac{\omega}{240}\right.\right|$$

(3-6)

The describing function is then:

$$N = \frac{\sqrt{A_1^2 + B_1^2}}{B} \quad \underline{/\theta} \qquad (3\text{-}7)$$

where

$$\theta = \mathrm{Tan}^{-1}(A_1/B_1)$$

Equations 3-5, 3-6, and 3-7 are suitable for evaluating the numerical value of the describing function. Due to their complex nature, the digital computer was used to overcome the labor required to calculate more than a limited number of points.

The computer program with numerical data is contained in Appendix A.

Since the describing function, which is derived above is dependent upon the frequency, the magnitude of the input, B, and the difference between constant level of the output and the reference speed α_0, separate sets of calculations are necessary for each choice of an independent variable. For convenience the magnitude of the input was chosen as the independent variable. The flow chart for the computer program is shown in Figure 3.3.

To make the prediction of limit cycle characteristic the describing functions were drawn on the Nichols chart. They are shown in Figures 3.4 through 3.6.

The values of alpha and frequencies for evaluation of describing functions were obtained from the simulation of the system which will be discussed later.

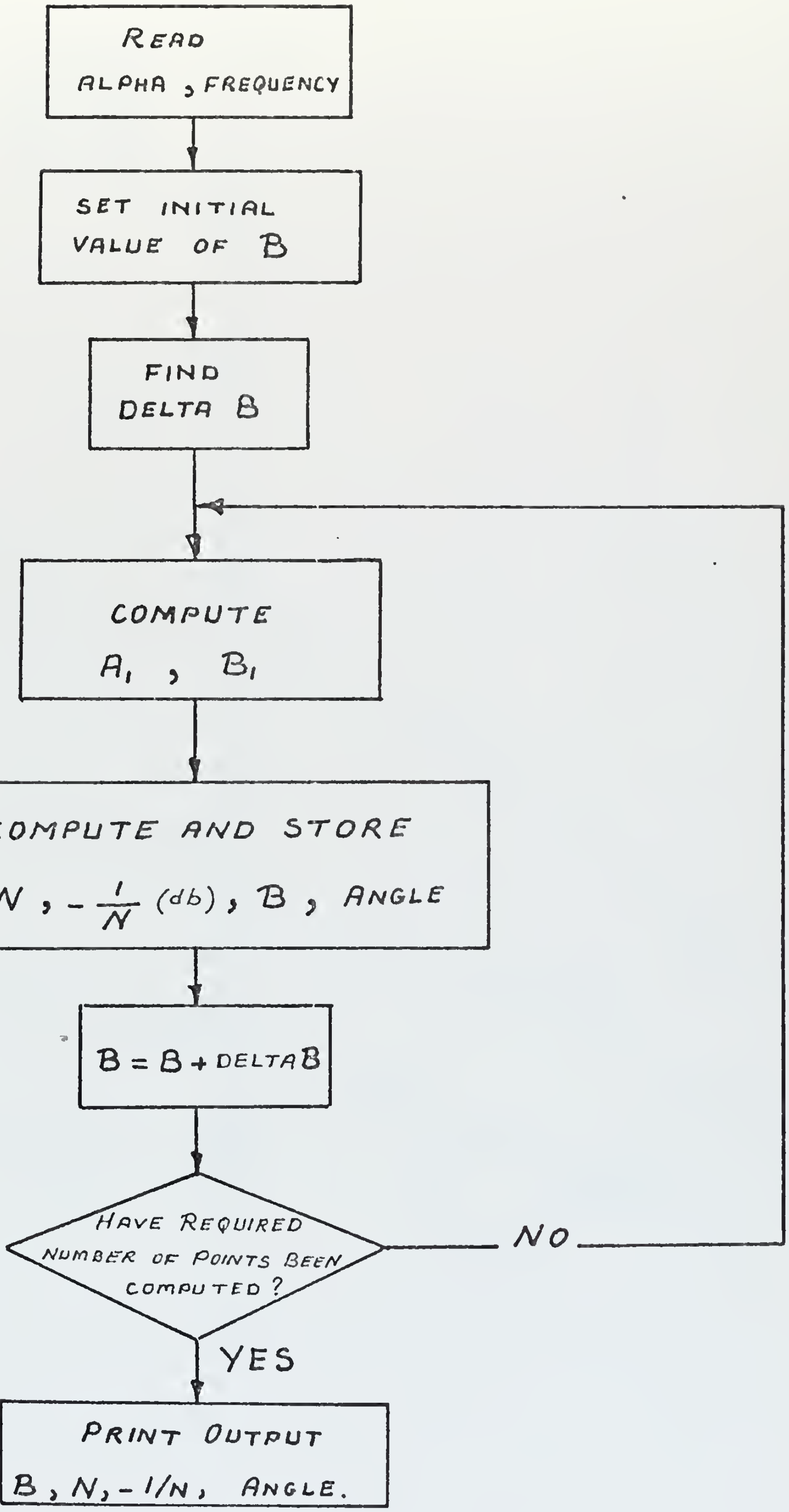
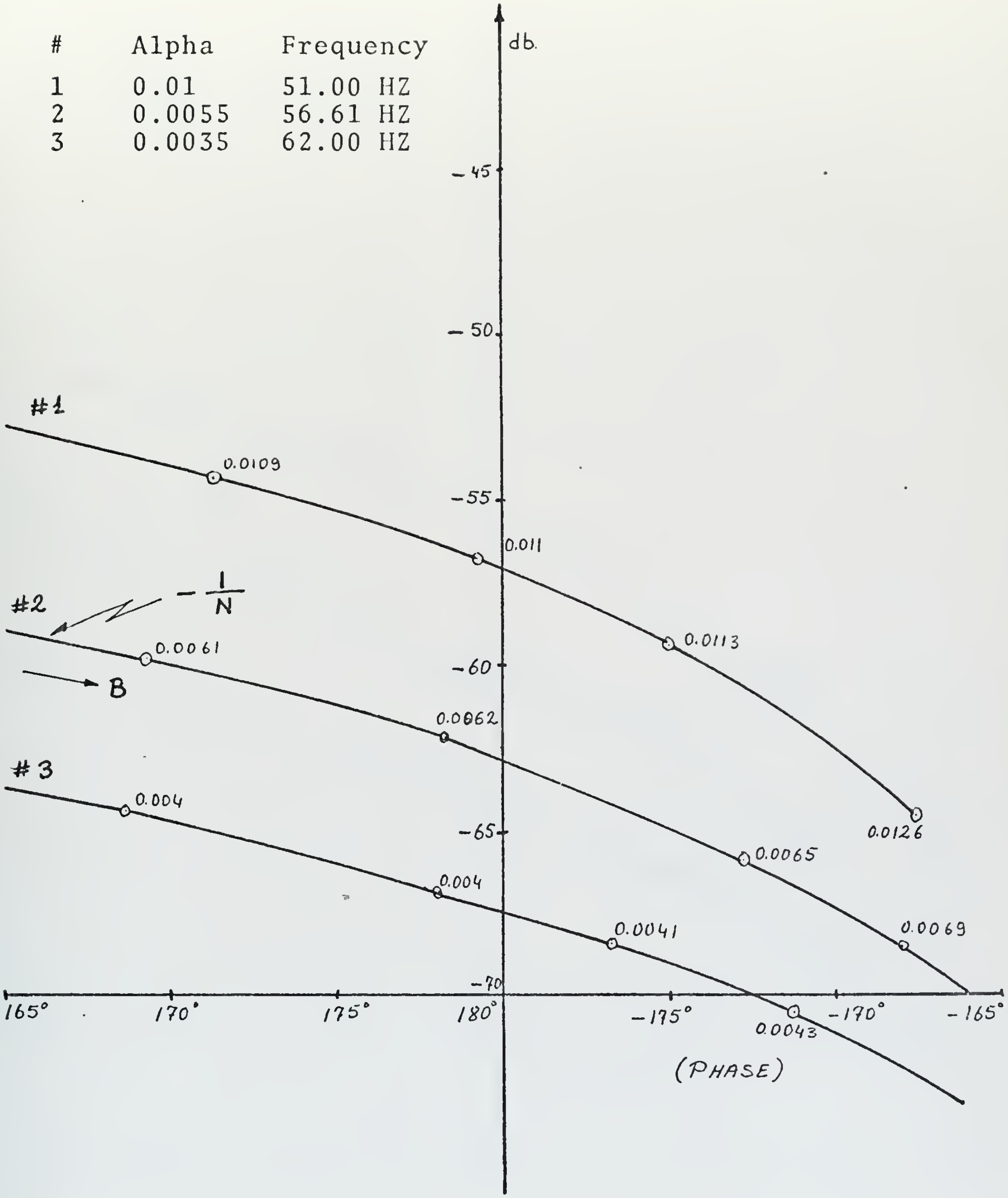
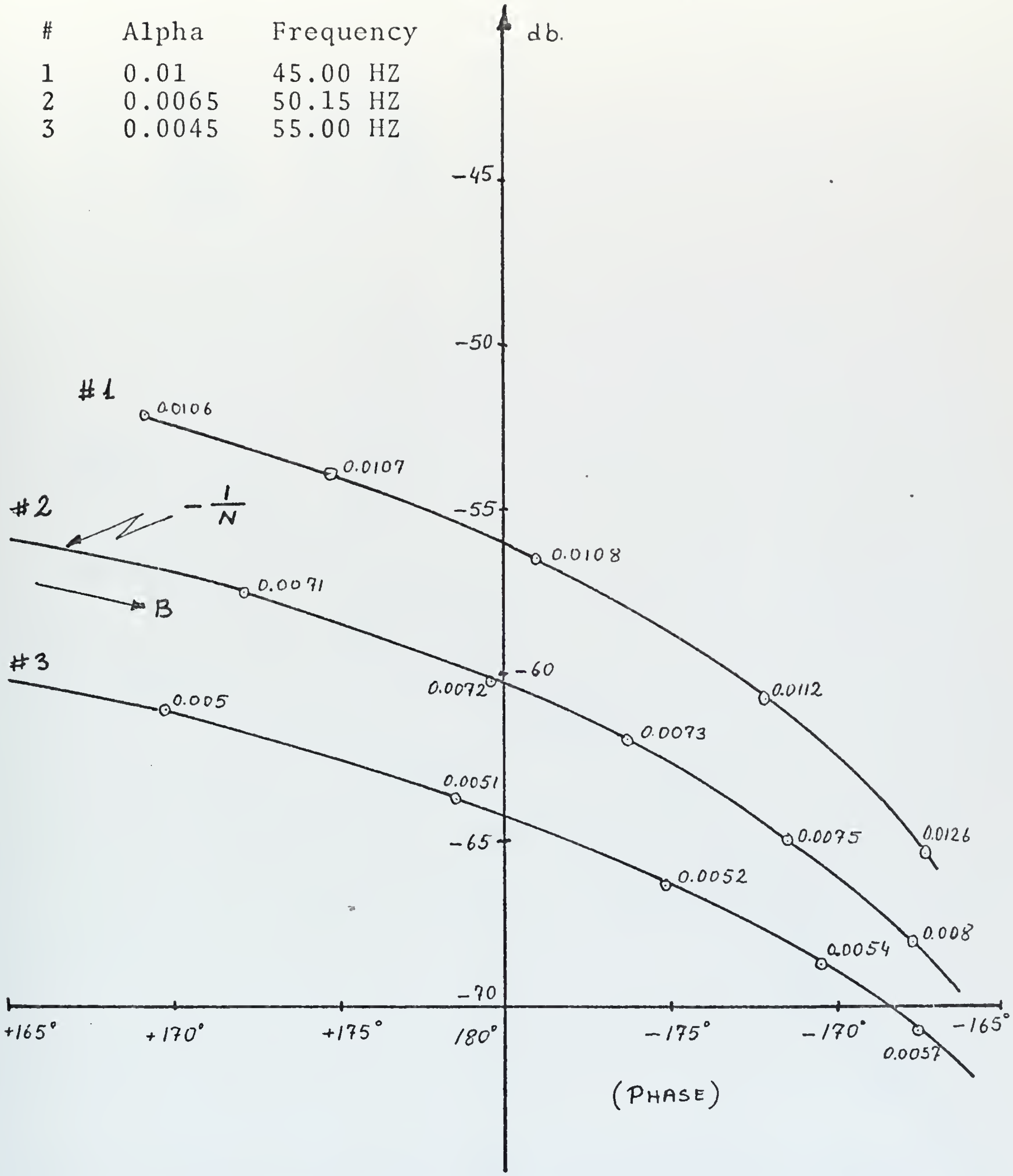


FIGURE 3.3: Flow chart to compute value of describing function.



#	Alpha	Frequency
1	0.01	51.00 HZ
2	0.0055	56.61 HZ
3	0.0035	62.00 HZ

FIGURE 3.4: Describing function (-1/N) for limit cycling thyristor rectifier bridge.



#	Alpha	Frequency
1	0.01	45.00 HZ
2	0.0065	50.15 HZ
3	0.0045	55.00 HZ

FIGURE 3.5: Describing function (-1/N) for limit cycling thyristor rectifier bridge.

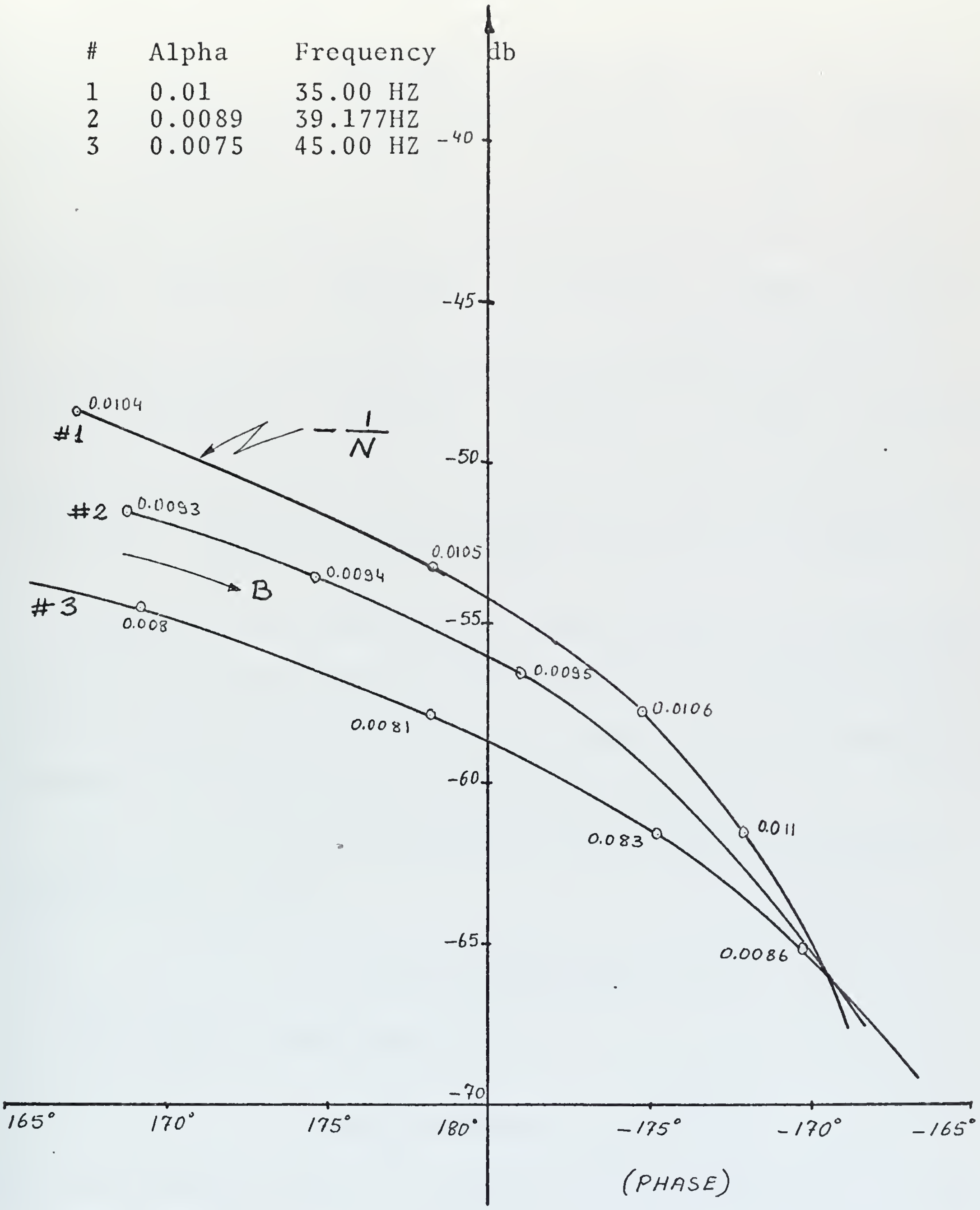


FIGURE 3.6: Describing function (-1/N) for limit cycling thyristor rectifier bridge.

These values were tabulated in Table 3-1.

V_r	ω_m	REFERENCE IN RAD/SEC	MEAN VALUE OF OUTPUT	ALPHA	FREQUENCY
31^V	930 rpm	97.4882	97.4843	0.0055	56.61HZ
32.8^V	984 rpm	103.1443	103.1378	0.0065	50.15HZ
33.5^V	1005 rpm	105.3459	105.337	0.0089	39.177HZ

TABLE 3-1. Tabulation of simulation results for V_r equal 31,32.8 and 33.5 Volts.

Having derived the transfer function for the linear portion of the system and describing function for the nonlinear part of the system there are now a number of ways to determine the condition necessary for limit cycling.

The characteristic equation for the system is written from equation 2-3 as:

$$1 + G_1(s)\ G_2(s)\ H(s)\ N = 0$$

This can be rearranged as:

$$G_1(s)G_2(s)H(s) = -\frac{1}{N} = G(s)$$

Thus the intersection of a graphical representation of G with -1/N determines the critical point at which limit cycling will occur. Either a Nyquist or a Nichols plot is convenient for this purpose. The choice of the Nichols plot for these analyses is arbitrary.

To determine the location of the limit cycle the describing function curves were superimposed on the frequency response curve of the linear part for frequency 39.177 HZ with alpha 0.0089, for frequency 50.15 HZ with alpha 0.0065, and for frequency 56.61 HZ with alpha 0.0055. The graphs are illustrated in Figures 3.7 through 3.9.

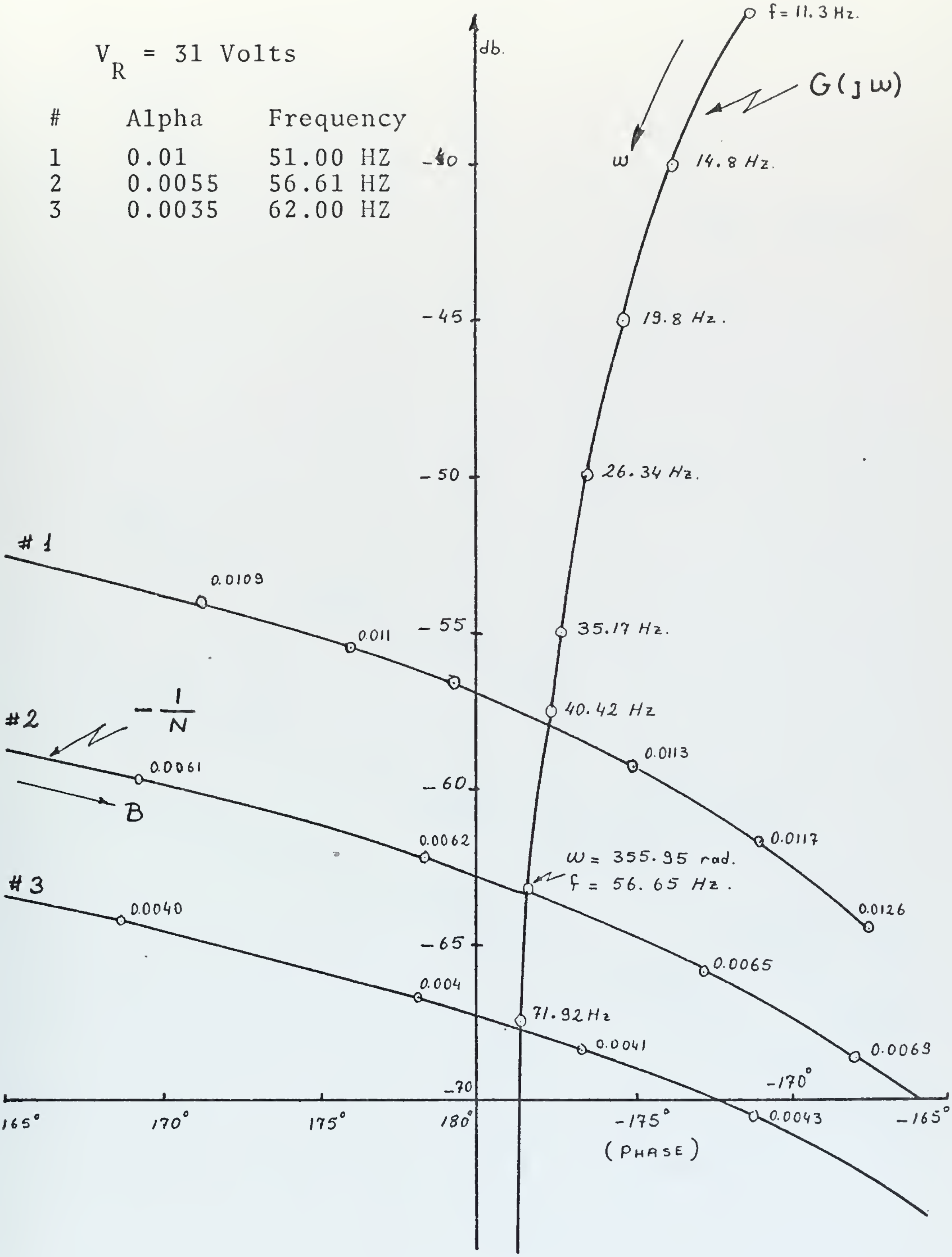
The values of frequency and amplitude were measured at intersections of G with -1/N. The results are tabulated in Table 3-2.

V_r	Amplitude of -1/N	Frequency of -1/N	Frequency of G
31.	0.0063	56.61 HZ	56.65 HZ
32.8	0.0072	50.15 HZ	50.13 HZ
33.5	0.0095	39.17 HZ	39.23 HZ

TABLE 3-2. Tabulation of the observed limit cycle frequency and amplitude.

From the comparison of the results in Table 3-2, it can be seen that the frequency of the -1/N curve and frequency of the G curve are very close to each other. This is true for all three cases.

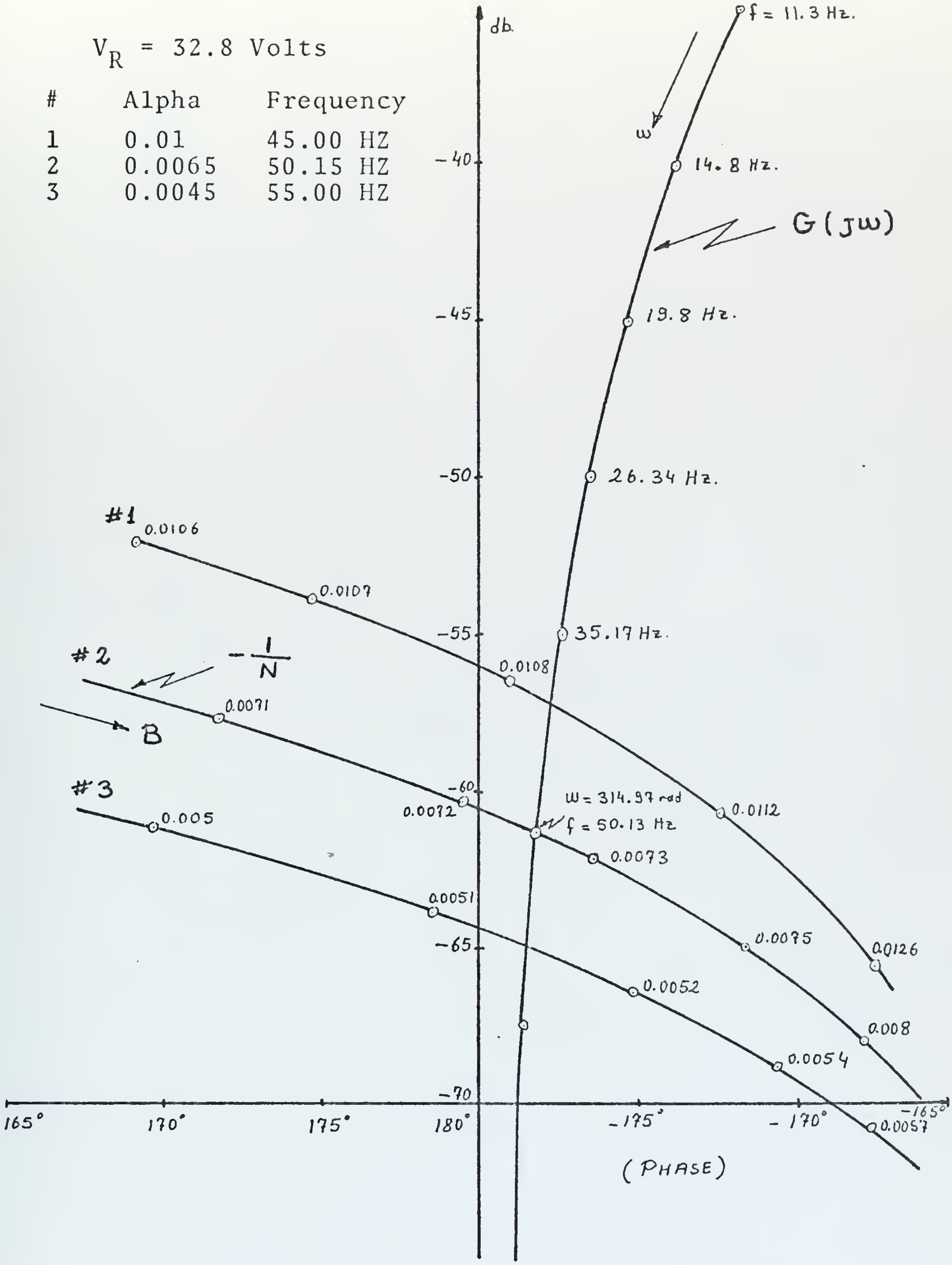
These results were obtained when alpha was equal to the values that are indicated in Table 3-1. Corresponding to these alpha values the amplitude of the limit cycle was found as indicated in Table 3-2.



V_R = 31 Volts

#	Alpha	Frequency
1	0.01	51.00 HZ
2	0.0055	56.61 HZ
3	0.0035	62.00 HZ

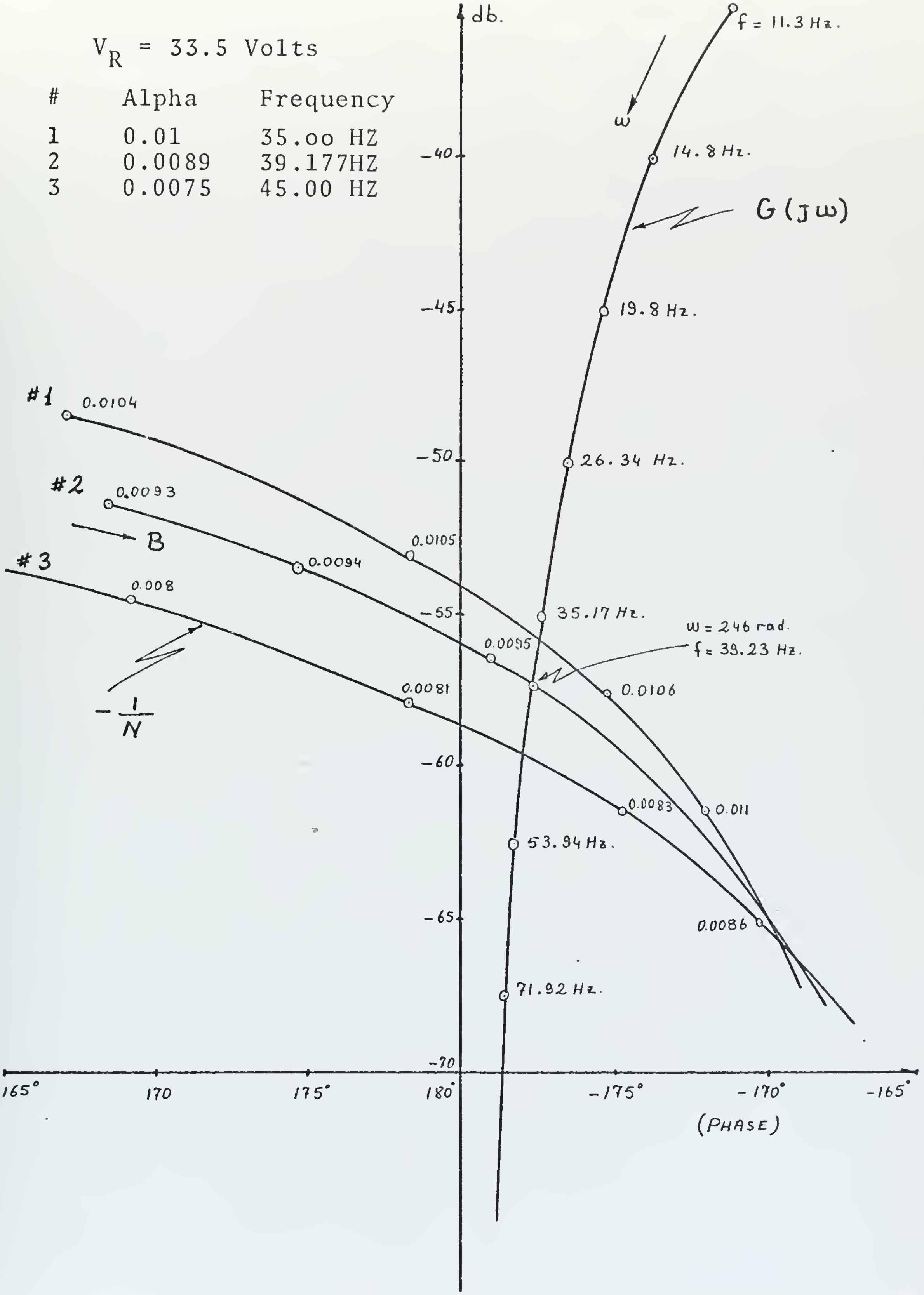
FIGURE 3.7.



V_R = 32.8 Volts

#	Alpha	Frequency
1	0.01	45.00 HZ
2	0.0065	50.15 HZ
3	0.0045	55.00 HZ

FIGURE 3.8.



V_R = 33.5 Volts

#	Alpha	Frequency
1	0.01	35.oo HZ
2	0.0089	39.177HZ
3	0.0075	45.00 HZ

FIGURE 3.9.

Thus there is good agreement with simulation results in both frequencies of the limit cycle and the values of alpha predicted by the describing function. This indicates the validity of the describing function in prediction of the limit cycle of the system.

IV. SIMULATION OF THE SYSTEM AND SUBHARMONIC EFFECTS

To determine the validity of the describing function and to see the performance of the system in the time domain, the system was simulated on the digital computer. The flow chart for the simulation is shown in Figure 4.1. Naval Postgraduate School computer library subroutine "INTEG 2" was used to solve the differential equations required in the simulation. The complete program is contained in Appendix B.

The supply voltage was considered to be a three-phase 60 cycle A-C source with a peak amplitude of 115 volts throughout the simulation.

The forcing voltage for the system, that is applied to the armature of the D-C motor is a three-phase, full-wave, rectified voltage during time a to b, a portion of a sine wave for the appropriate conduction phase during time b to c, and zero voltage with no reverse current through the inductance during c to T of Figure 3.2.

Graphical output from this program are shown in Figure 4.2 illustrating the input voltage wave form, and Figures 4.3 through 4.7 illustrating the output speed wave forms.

Simulation was performed by changing the reference from 930 r.p.m. to 1260 r.p.m. These are shown in Table 4-1.

When a linear system is driven with a sinusoidal input it is known that the steady state output is also a sinusoid, differing from the input in amplitude and phase but having precisely the same frequency. For linear systems, that is

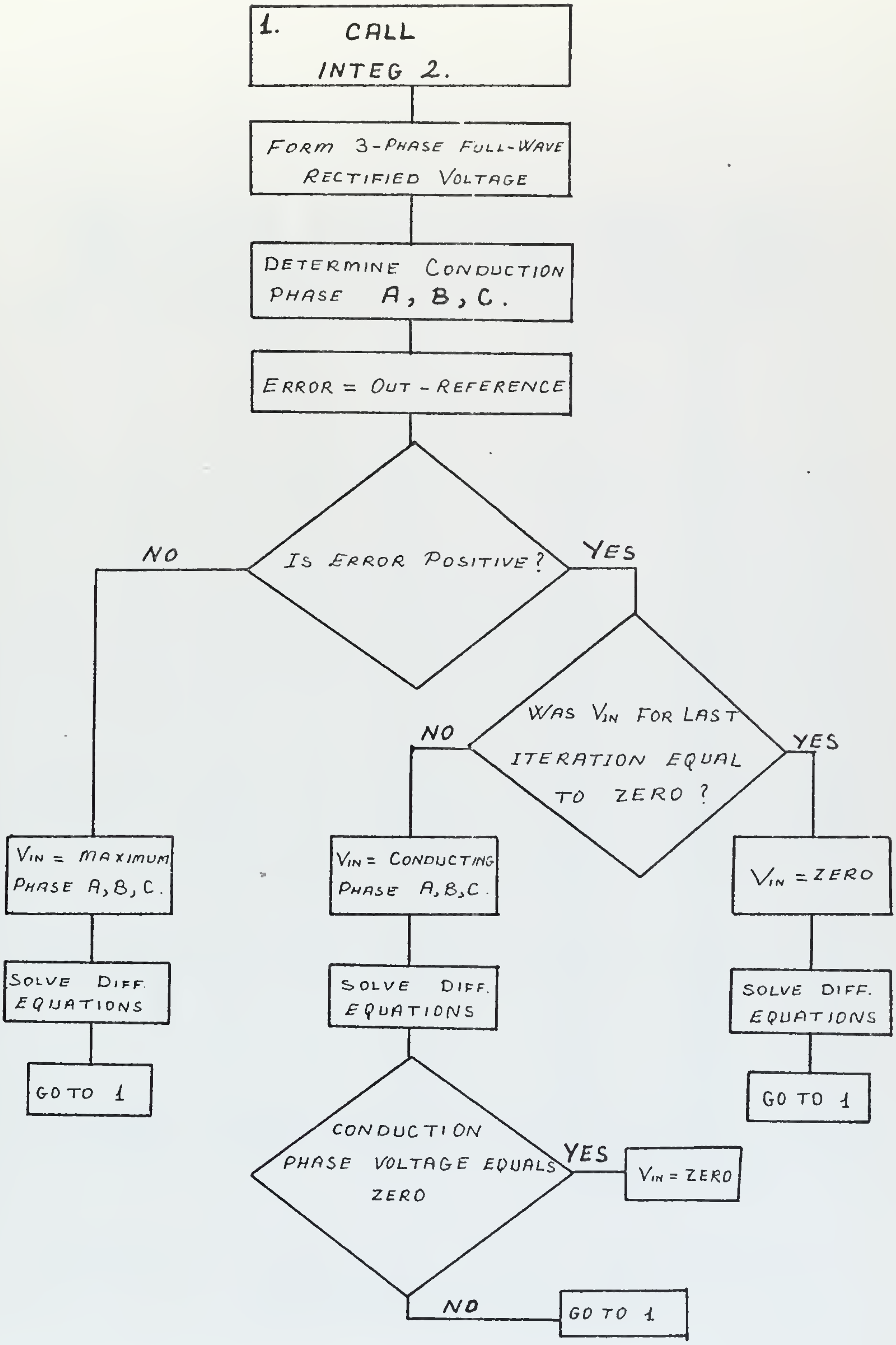

1. CALL INTEG 2.
FORM 3-PHASE FULL-WAVE RECTIFIED VOLTAGE
DETERMINE CONDUCTION PHASE A, B, C.
ERROR = OUT - REFERENCE
IS ERROR POSITIVE?
NO
YES
WAS V_IN FOR LAST ITERATION EQUAL TO ZERO ?
NO
YES
V_IN = MAXIMUM PHASE A, B, C.
V_IN = CONDUCTING PHASE A, B, C.
V_IN = ZERO
SOLVE DIFF. EQUATIONS
SOLVE DIFF. EQUATIONS
SOLVE DIFF. EQUATIONS
GO TO 1
GO TO 1
CONDUCTION PHASE VOLTAGE EQUALS ZERO
YES
V_IN = ZERO
NO
GO TO 1

FIGURE 4.1. Flow chart for simulation.

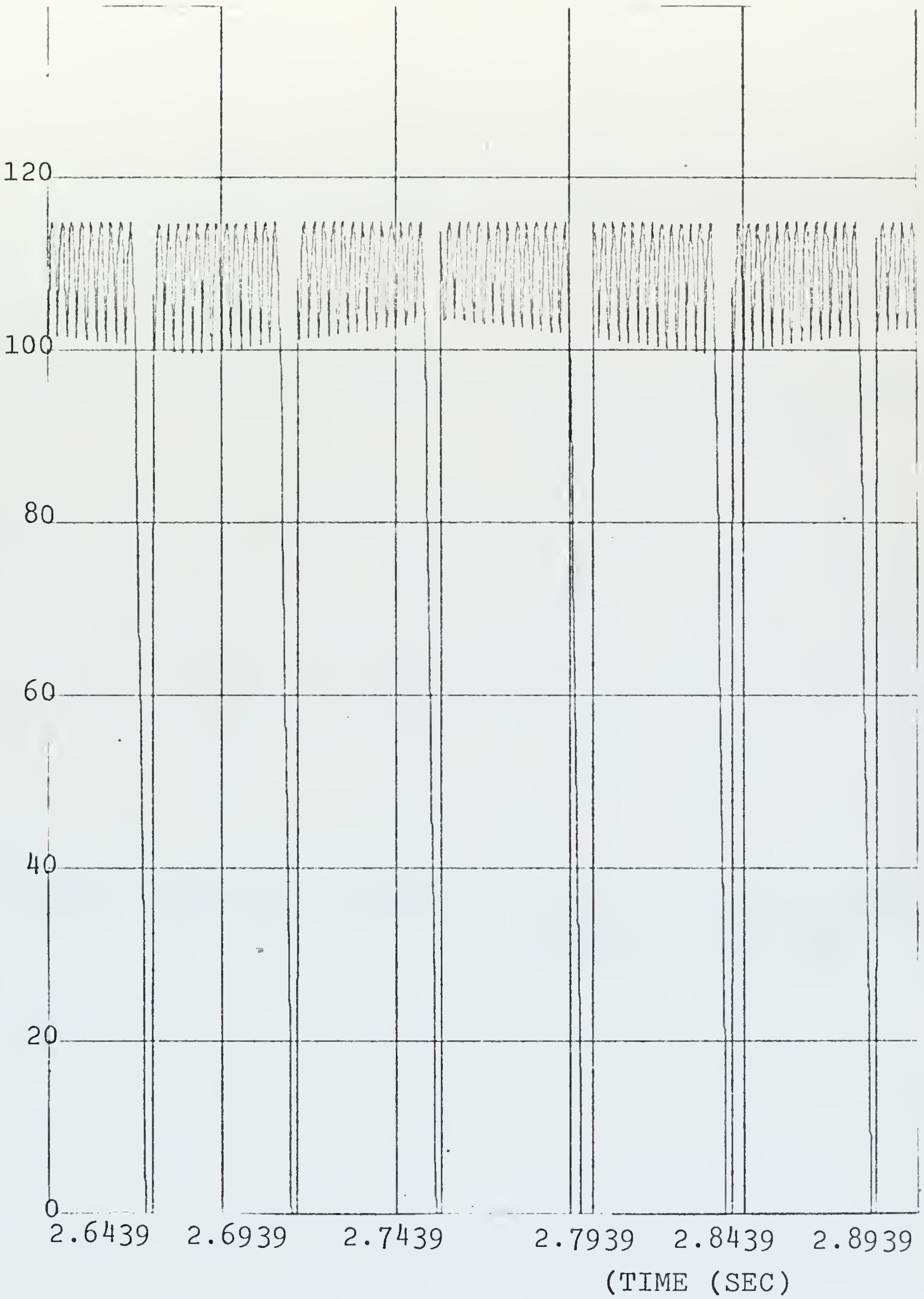
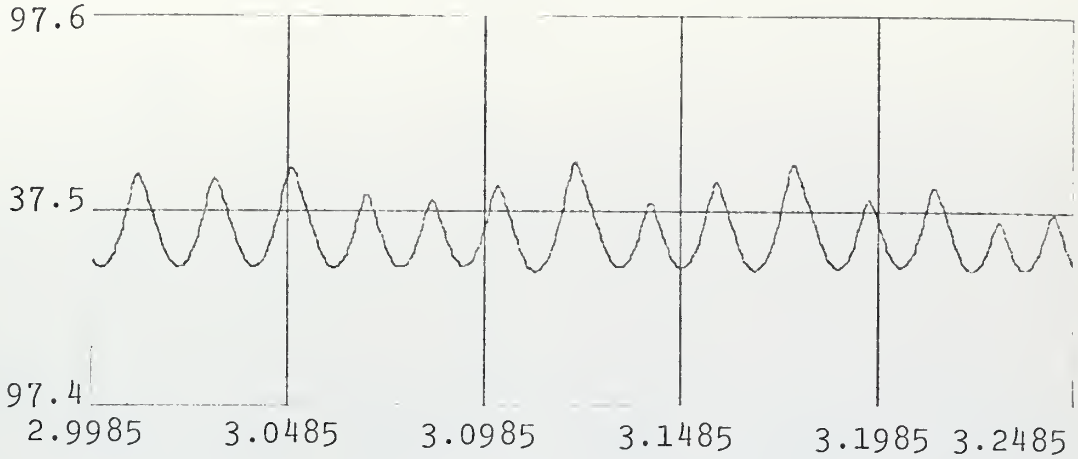
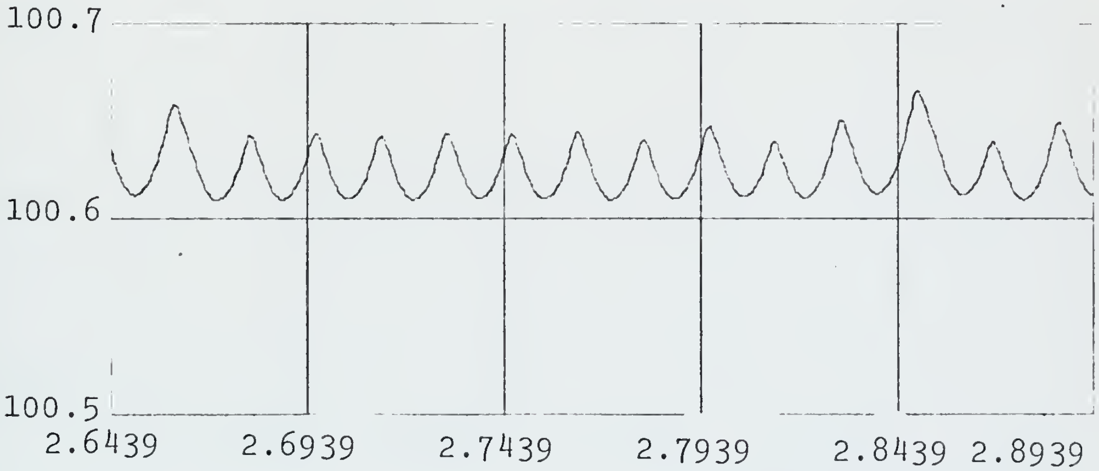


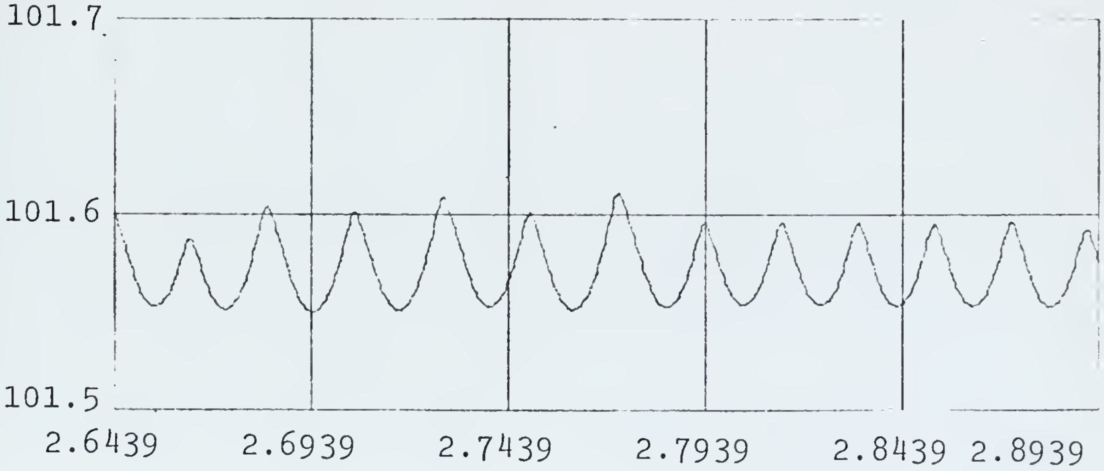
FIGURE 4-2. Simulation results, input voltage. Reference speed 1050 rpm.



Reference = 930 rpm

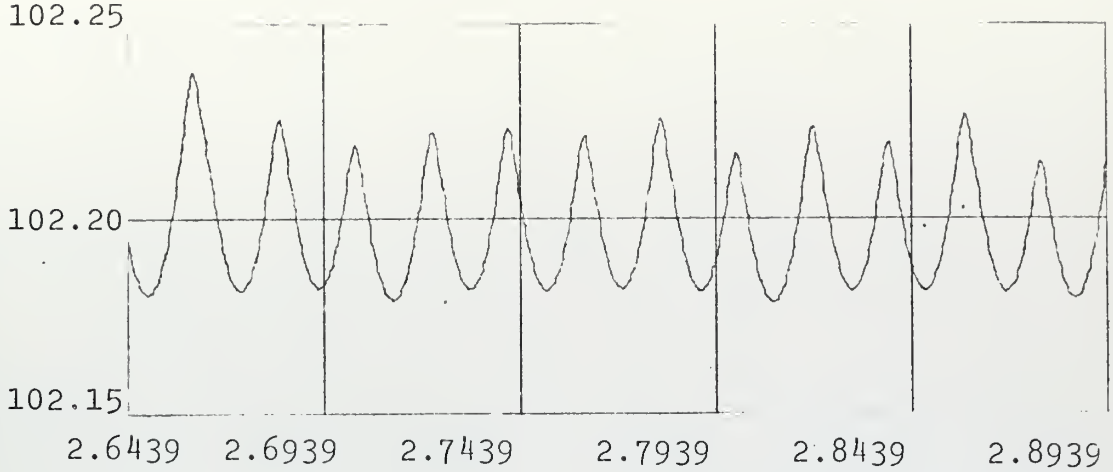


Reference = 960 rpm

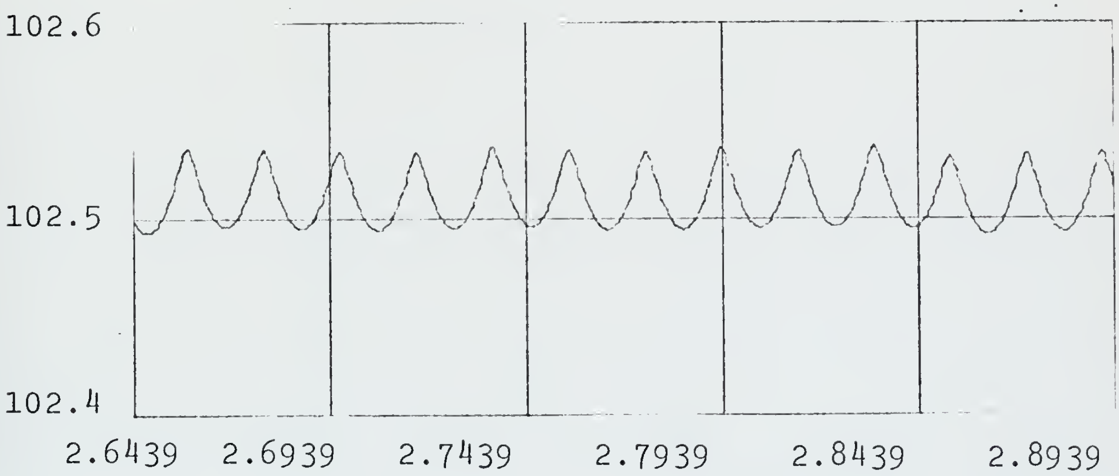


Reference = 969 rpm

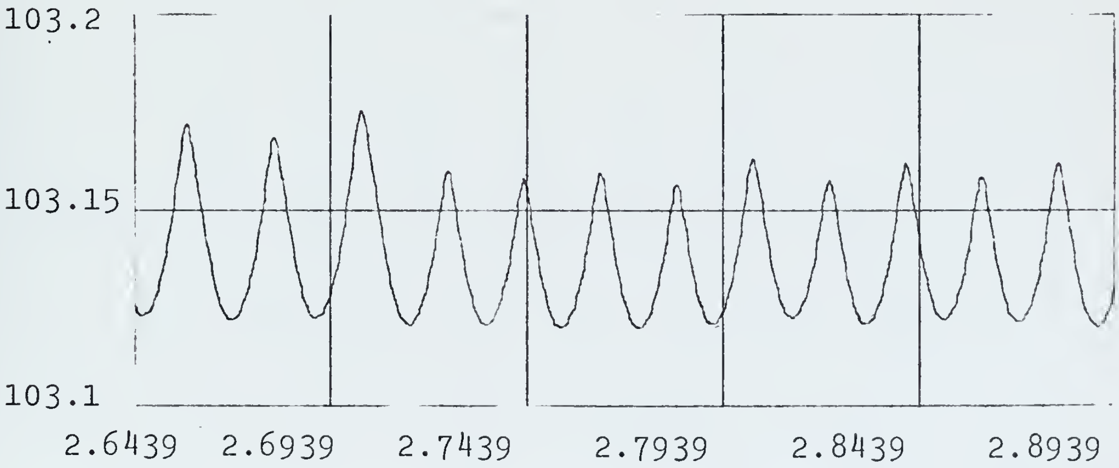
FIGURE 4-3. Simulation results, output speed.



Reference = 975 rpm

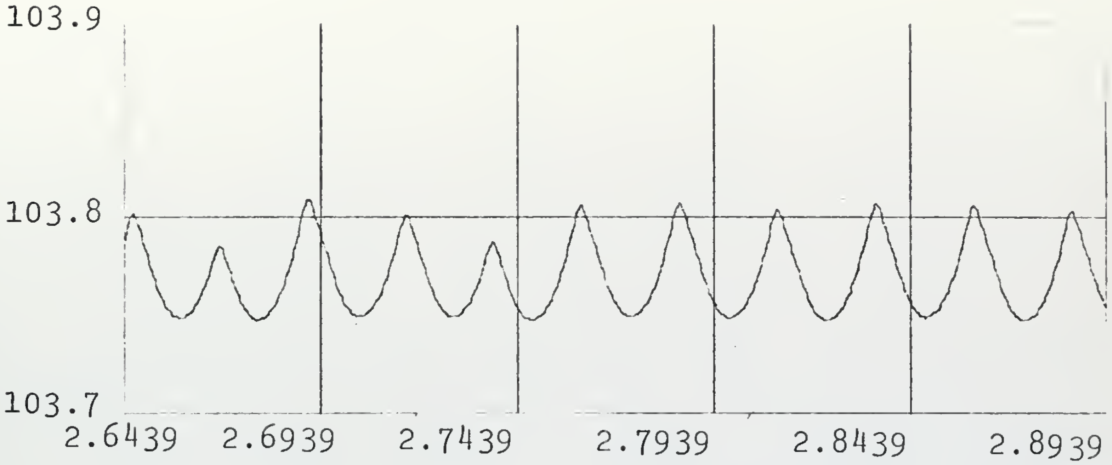


Reference = 978 rpm

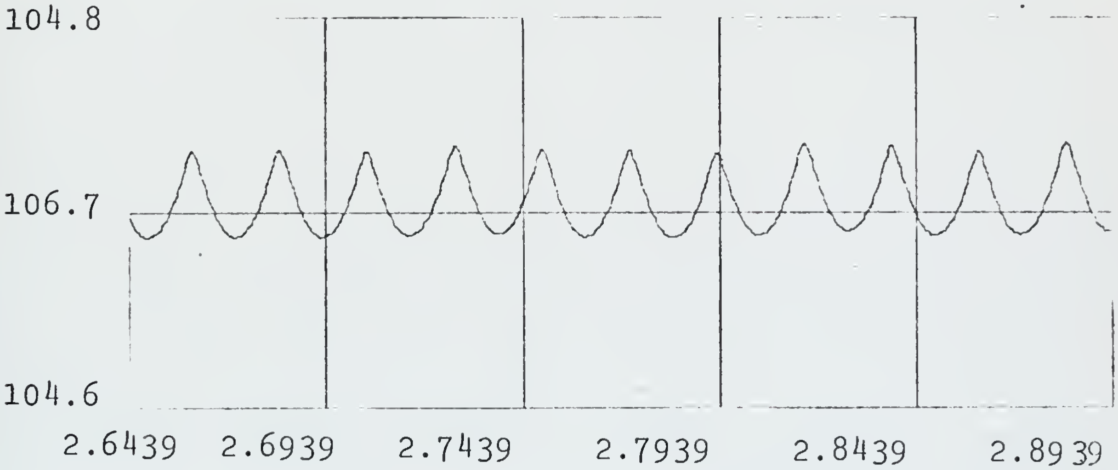


Reference = 984 rpm

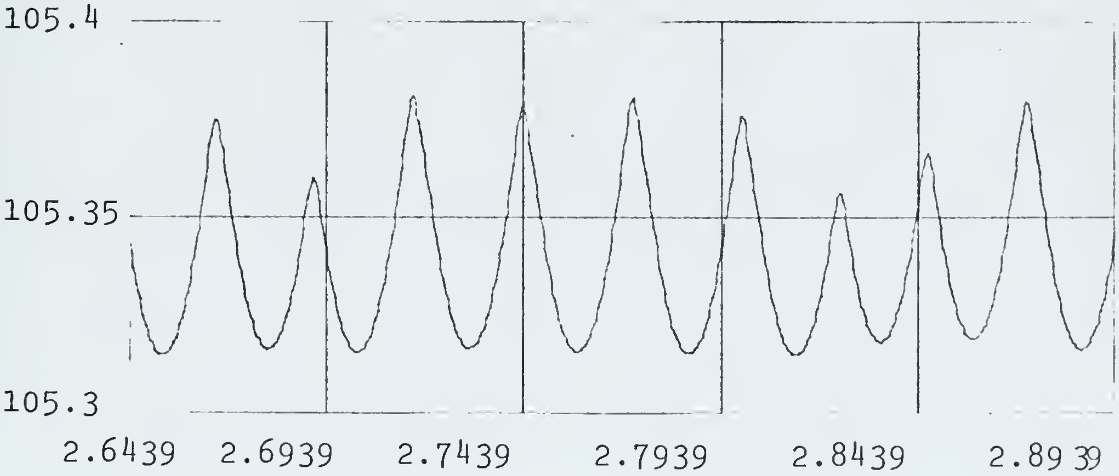
FIGURE 4-4. Simulation results, output speed



Reference = 990 rpm

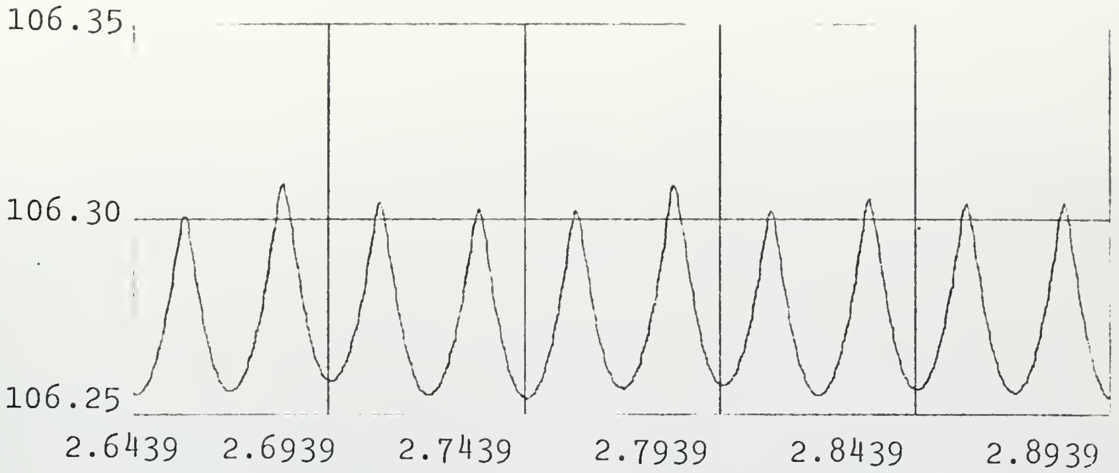


Reference = 999 rpm

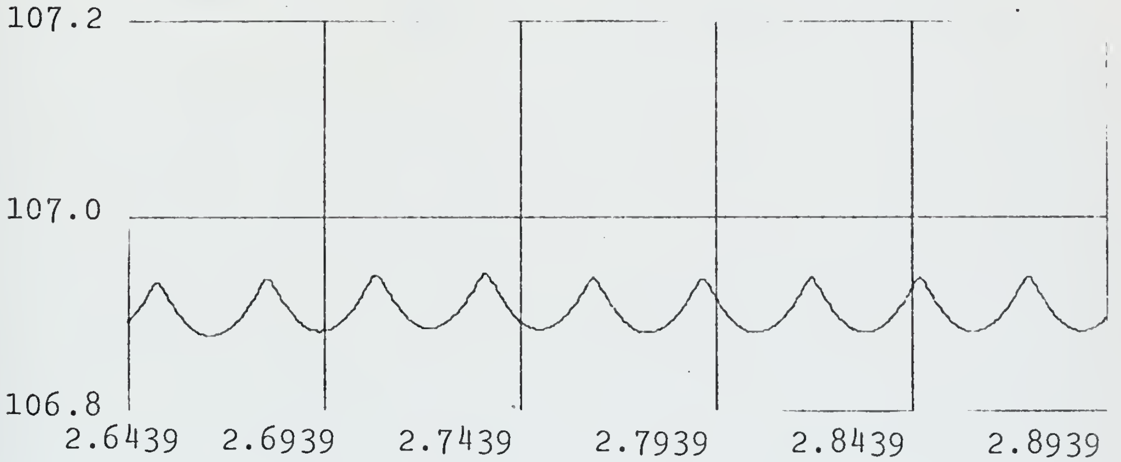


Reference = 1005 rpm

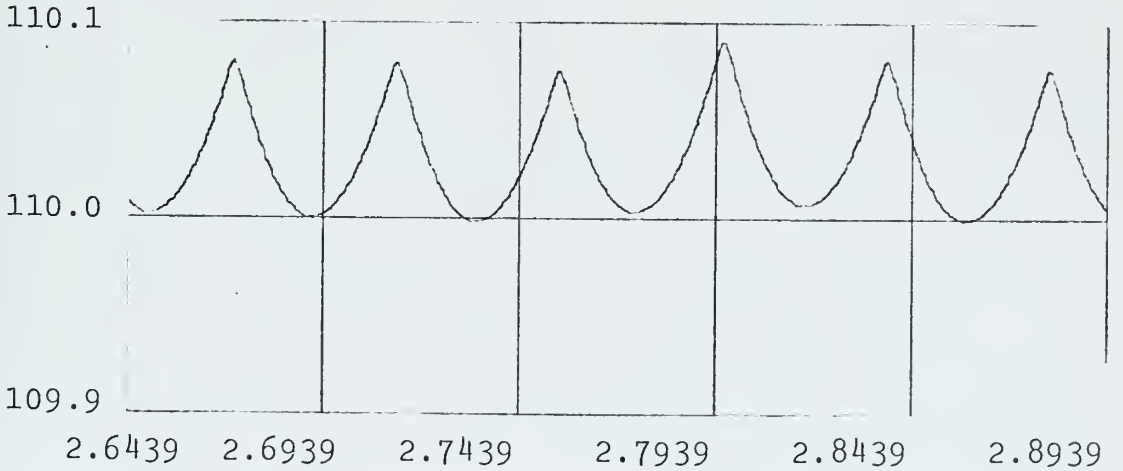
FIGURE 4-5. Simulation results, output speed.



Reference = 1014 rpm



Reference = 1020 rpm



Reference = 1050 rpm

FIGURE 4-6. Simulation results, output speed.

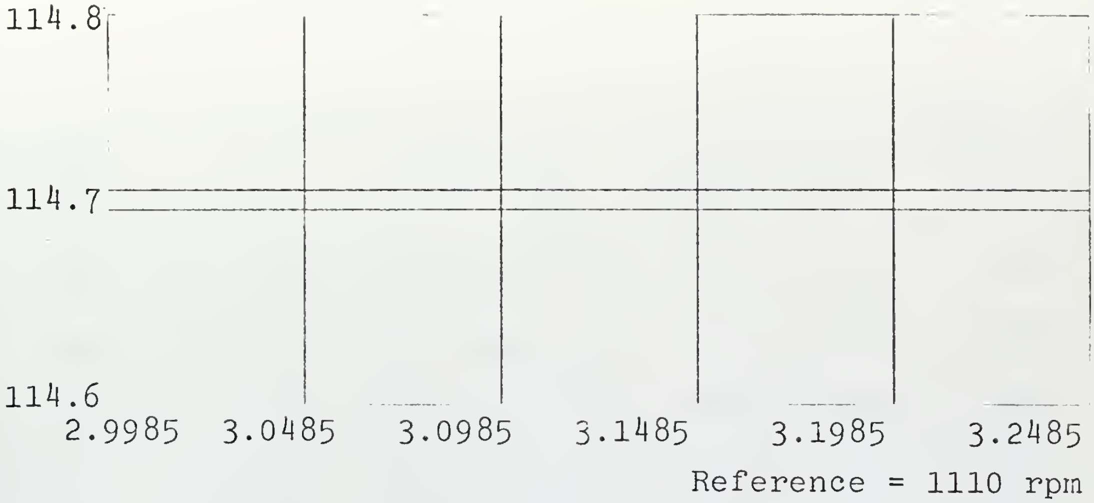


FIGURE 4-7. Simulation results, output speed.

REFERENCE VOLTAGE	SPEED	PERIOD OF LIMIT CYCLE	FREQUENCY OF LIMIT CYCLE	DOES SUB-HARMONIC EXIST?
31 volt	930 rpm	0.017663 Sec	56.61 HZ	YES
32 volt	960 rpm	0.017631 Sec	56.71 HZ	YES
32.3 volt	969 rpm	0.021173 Sec	47.28 HZ	YES
32.5 volt	975 rpm	0.019924 Sec	50.14 HZ	YES
32.6 volt	978 rpm	0.0195 Sec	51.28 HZ	YES
32.8 volt	984 rpm	0.01994 Sec	50.13 HZ	YES
33. volt	990 rpm	0.02391 Sec	41.82 HZ	YES
33.3 volt	999 rpm	0.0223 Sec	44.576 HZ	YES
33.5 volt	1005 rpm	0.025525 Sec	39.177 HZ	YES
33.8 volt	1014 rpm	0.02545 Sec	39.293 HZ	YES
34. volt	1020 rpm	0.027838 Sec	35.923 HZ	YES
35. volt	1050 rpm	0.0394 Sec	25.4 HZ	YES
37. volt	1110 rpm	NO	LIMIT	CYCLE
40. volt	1200 rpm	NO	LIMIT	CYCLE
42. volt	1260 rpm	NO	LIMIT	CYCLE

TABLE 4-1. Tabulation of simulation results.

true at all frequencies. In the case of a nonlinear system a sinusoidal input does not guarantee an output which is a sinusoid. In the usual case, the output wave contains harmonic frequency components which are integral multiples of the forcing frequency. In some cases, the output wave may contain one or more frequencies which are lower than the forcing frequency. Characteristically, these frequencies are integral submultiples of the forcing frequency which are called subharmonic frequencies. The amplitude of the subharmonic component may be small compared with the amplitude of the component at the driving frequency, or it may be so large that the driving frequency may be neglected for particular computations.

If the output wave shapes in Figure 4.3 through 4.7 are inspected, it is observed that the wave forms have a ripple instability which is small in amplitude compared to the average ripple amplitude. One can think this instability is caused by subharmonic effects of the system. It can be observed by inspection, but it is not possible to obtain its frequency and its amplitude from the output wave shapes, because they do not have a regular pattern. To figure out this instability, the Fourier analysis of the output wave shapes for reference speed 930, 984, and 1005 r.p.m. were made. During the Fourier analysis, several limit cycle periods were taken as a fundamental period of the Fourier, then the same harmonics of these fundamental frequencies which are also subharmonics of the limit cycle were obtained. From these results, amplitude and the order of subharmonic components of

the limit cycle in the output wave were calculated. These were tabulated in Table 4-2 through 4-4.

In Figure 4.8 through 4.10, the amplitude of the subharmonics was drawn to see the relative heights of the components. In Figure 4.8, it is seen that, at reference speed 930 r.p.m. 1/8 and 1/16 subharmonics have larger amplitude compared to others. Their amplitudes are approximately 15.6 percent of the output ripple amplitude. In Figure 4.9 which was drawn for reference speed 984 r.p.m., 1/2 subharmonic has larger amplitude and it is equal 25.3 percent of the output ripple. In Figure 4.10, which is for reference speed 1005 r.p.m. the largest subharmonic is 1/7. It has amplitude 16.1 percent of the ripple amplitude.

LIMIT CYCLE AMPLITUDE	ORDER OF SUBHARMONIC # OF CYCLE	1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/16
0.01982	4	0.00314		0.00323					
0.01786	8	0.00104		0.00086				0.00282	
0.01872	12	0.00093	0.00273	0.00117		0.00105			
0.01871	14	0.00074					0.00176		
0.01296	16	0.00063		0.00146				0.00290	0.00237
0.01231	18	0.00171	0.00207			0.00081			
0.01135	20	0.00205		0.00136	0.00183				
0.00882	24	0.00145	0.00130	0.00066		0.00107		0.00130	
0.01507	Average	0.00146	0.00203	0.00145	0.00183	0.00098	0.00176	0.00234	0.00237

TABLE 4-2: Tabulation of Fourier analysis for V_R = 31 Volts.

LIMIT CYCLE AMPLITUDE	ORDER OF SUBHARMONIC # OF CYCLE	1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/16
0.01803	4	0.00830		0.00279					
0.01807	8	0.00516		0.00302				0.00065	
0.01626	12	0.00406	0.00099	0.00230		0.00148			
0.01576	14	0.00296					0.00017		
0.01526	16	0.00179		0.00160				0.00100	0.00197
0.01456	18	0.00256	0.00039			0.00148			
0.01276	20	0.00326		0.00182	0.00029				
0.01648	24	0.00388	0.00050	0.00065		0.00125		0.00062	
0.01590	Average	0.00407	0.00063	0.00203	0.00029	0.00140	0.00017	0.00076	0.00197

TABLE 4-3: Tabulation of Fourier analysis for V_R = 32.8 Volts.

LIMIT CYCLE AMPLITUDE	ORDER OF SUBHARMONIC								
	# OF CYCLE	1/2	1/3	1/4	1/5	1/6	1/7	1/8	1/16
0.02045	4	0.00359		0.00343					
0.02180	8	0.00162		0.00427				0.00132	
0.01901	12	0.00274	0.00242	0.00187		0.00309			
0.01944	14	0.00212					0.00326		
0.02020	16	0.00252		0.00273				0.00232	0.00146
0.02015	18	0.00172	0.00298			0.00279			
0.02150	20	0.00152		0.00286	0.00116				
0.01944	24	0.00175	0.00262	0.00226		0.00146		0.00231	
0.02025	Average	0.00220	0.00267	0.00290	0.00116	0.00245	0.00326	0.00199	0.00146

TABLE 4-4: Tabulation of Fourier analysis for V_R = 33.5 Volts.

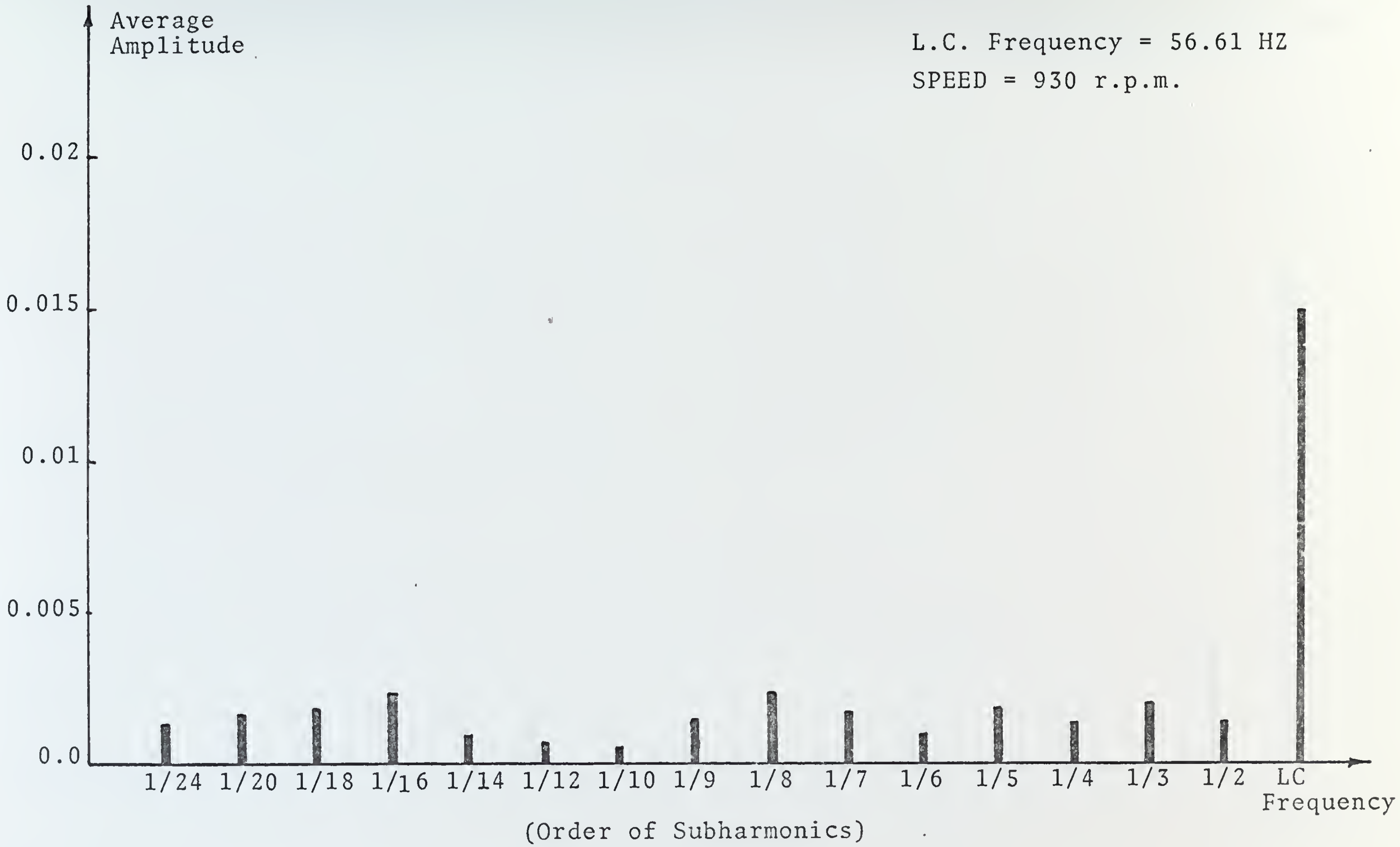


FIGURE 4.8: Average amplitudes of the subharmonics for V_R = 31 Volts.

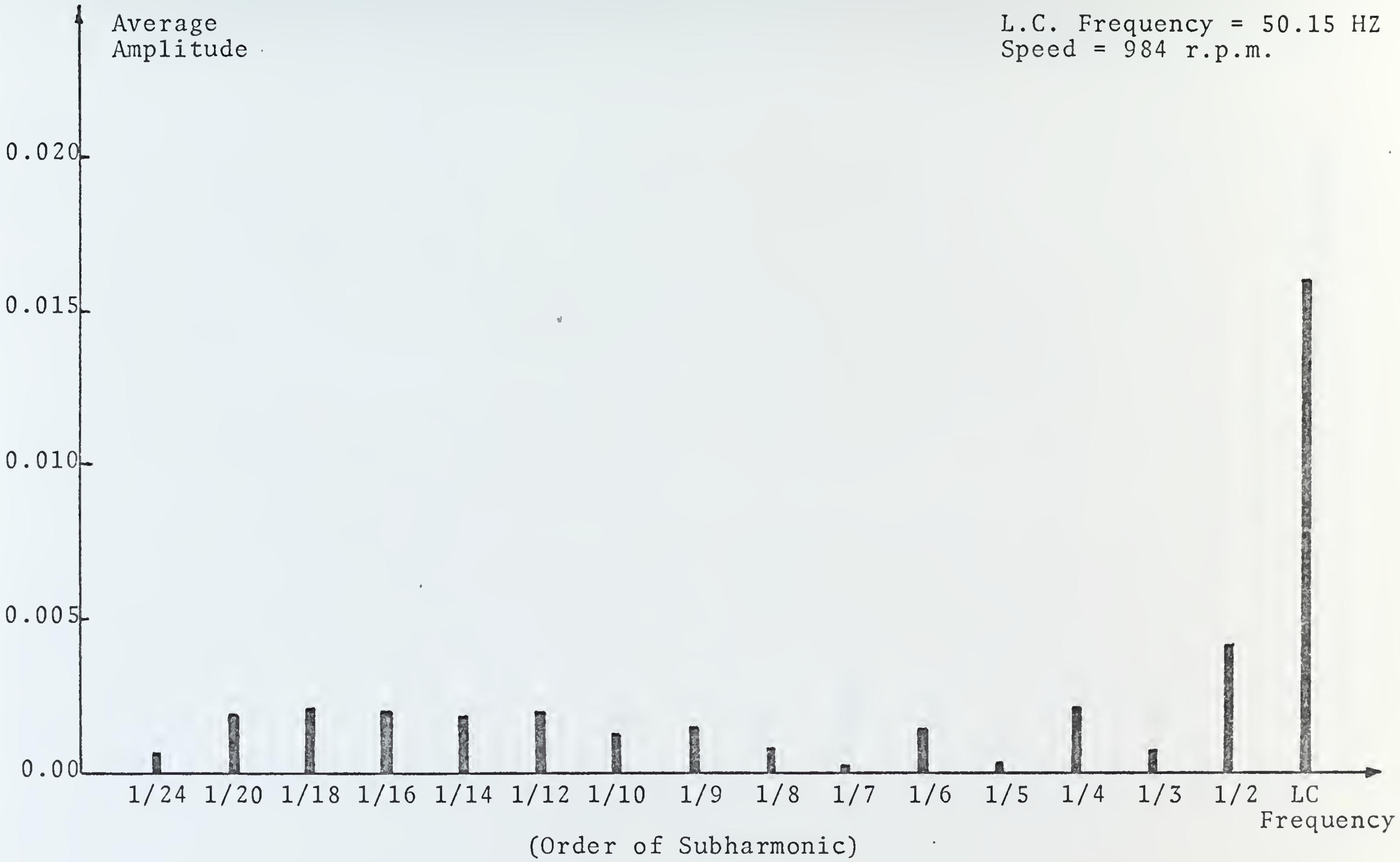


FIGURE 4.9: Average amplitude of the subharmonics for V_R = 32.8 Volts.

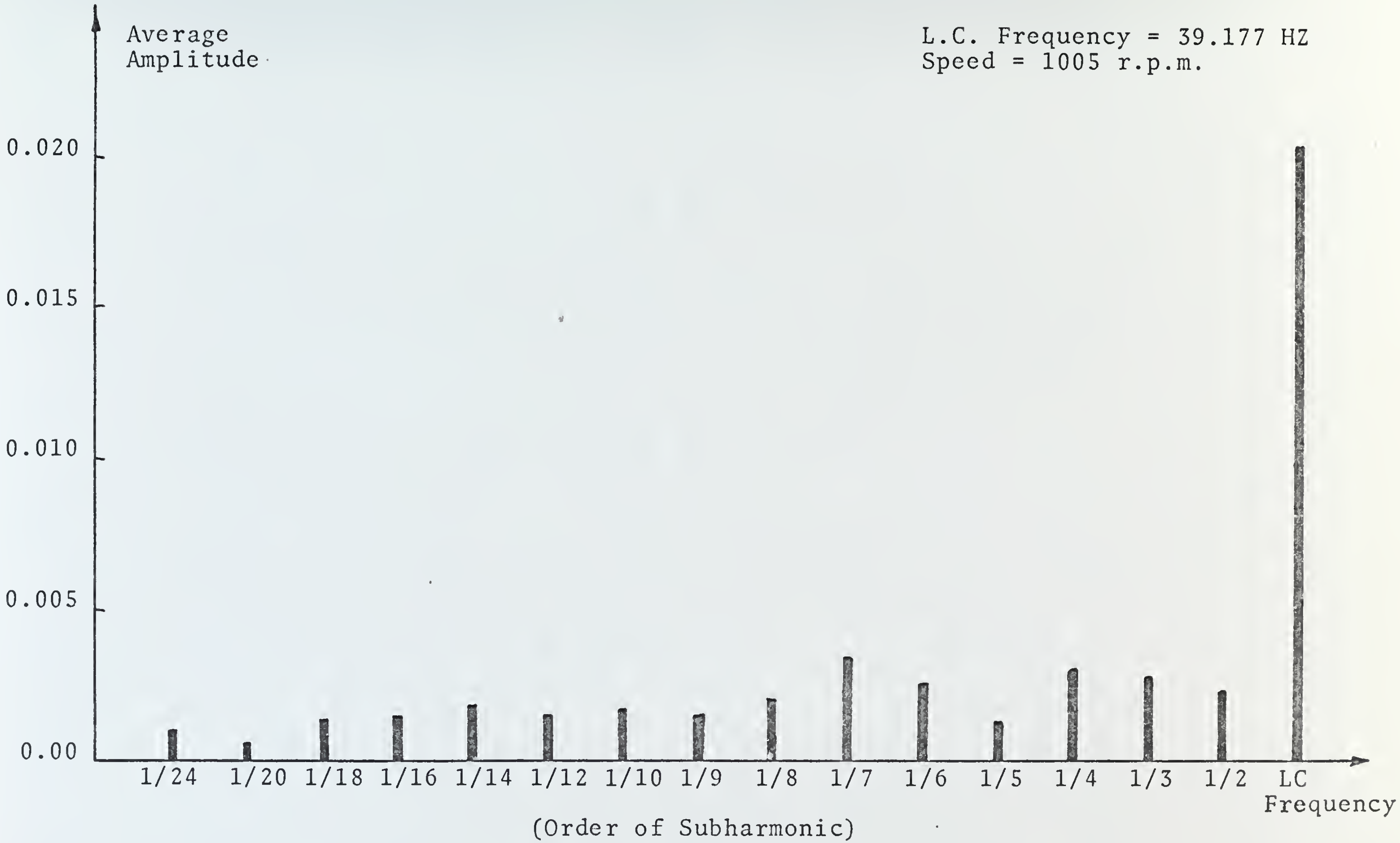


FIGURE 4.10: Average amplitudes of the subharmonics for V_R = 33.5 Volts.

V. CONCLUSION AND RECOMMENDATION FOR FURTHER STUDY

The main conclusion that might be reached in reviewing the experimental results is that the D-C motor at constant field current operates at an almost constant speed, and its speed may be controlled over wide ranges by armature-voltage control. This can be seen from Figures 4.3 through 4.7. If these figures are inspected closely it can be observed that the ripple amplitudes are very small compared to the output value. They are approximately within the ± 0.025 percent of the desired value of the output. This may be acceptable for most of the applications in the industry.

Armature-voltage control was performed by adjusting the conduction phase of the thyristor-rectifier bridge. This causes the limit cycling in the control loop.

The describing function derived in Chapter III provides a mean by which the nonlinearity of the system can be represented and the overall performance of the system analyzed. It is possible to predict the approximate frequency and amplitude of the limit cycle as illustrated in Figures 3.7 through 3.9. In order to predict the response more precisely, it is necessary to predetermine the value of alpha, that might be done by simulating the system and measuring the output mean value then taking the difference between output mean value and reference.

One tentative conclusion that can be achieved by examination of the experimental data is that, under certain conditions

the forced-limit-cycling speed control system will have subharmonic ripple instability.

The describing function derived accounts only for the first harmonic of the output voltage from the nonlinear portion of the system and assumes that higher harmonics are negligible. However, as seen in Figures 4.3 through 4.7 the other harmonics can exist. In some cases these harmonics can be submultiples of the limit cycle frequency.

In this study Fourier analysis was performed to see whether the subharmonic exists or not. As a result Tables 4-2 through 4-4 and Figures 4.8 through 4.10 were obtained. These show that the ripple instability is caused by subharmonic effects of the system nonlinearity. But this is not good enough to predict the existence of the subharmonic in the output of the system. It can give some insight about the nature of the problem. There are no general rules available which define the conditions necessary for the occurrence of the subharmonic oscillation. For mathematical analysis several of the references noted in the List of References suggest that a possible method of prediction of the subharmonic ripple instability in the system would be to employ a Dual Input Describing Function. Any further study should give some consideration to these analytical methods to understand ripple instability and existence of the subharmonic.

Another area for study is to increase the gain and see the effect of the gain on the ripple instability. This may require some sort of compensation network to eliminate the instability in the output for a range of gain values.

APPENDIX A

Computer program for computing value of describing curves. Numerical data for -1/N curves plotted in Figure 3.4 through 3.9.

```
      DIMENSION X(1500),Y(1500),Z(1500),YY(1500)
      PI=3.141592
      FREQ=45.0
      ALPHA=0.01
      C5=ALPHA
      T=1.0/FREQ
      XPHI=3.0*FREQ/(4.0*57.29578)
      XRAN=C5*((1.1/COS(XPHI))-1.0)
      XINC=XRAN/50.0
      B=C5+XINC
      C3=PI/(120.0*T)
      DO 200 J=1,50
      NPT=J
      NJ=J
      C1=1.0/(B*PI)
      DOG=B**2-C5**2
      IF(DOG)300,300,301
  300 C2=0.0
      GO TO 302
  301 C2=SQRT(DOG)
  302 CONTINUE
      A1=C1*(-C5+(1.0/C3)*(C2-C2*COS(C3)+C5*SIN(C3)))
      B1=C1*(-C2+(1.0/C3)*(C5*(1.0-COS(C3))-C2*SIN(C3))))
      X(J)=B
      Y(J)=(SQRT(A1**2+B1**2))*110.0/B
      Z(J)=57.29578*ATAN2(A1,B1)
      YY(J)=20.0*(ALOG10(Y(J)))
      Z(J)=-Z(J)
      YY(J)=-YY(J)
      B=B+XINC
  200 CONTINUE
      WRITE(6,101)
  101 FORMAT(1H1,//,T24,'DESCRIBING FUNCTION DATA',/)
      WRITE(6,401) FREQ
  401 FORMAT(T24,'FREQUENCY = ',F6.3,//)
      WRITE(6,402) ALPHA
  402 FORMAT(T24,'ALPHA = ',F6.4,//)
      WRITE(6,107)
  107 FORMAT(T19,'B',T31,'N',T42,'PHASE',T56,'-1/N(DB)',//)
      DO 201 J=1,50
  201 WRITE(6,102) X(J),Y(J),Z(J),YY(J)
  102 FORMAT(14X,F6.4,6X,F9.4,6X,F7.2,6X,F8.4)
      CONTINUE
      STOP
      END
```

```
           DESCRIBING FUNCTION DATA

           FREQUENCY = 51.000

           ALPHA = 0.0100

     B                 N                PHASE            -1/N(DB)

0.0101         1401.8879            29.27           -62.9343
0.0102         1060.7751            32.61           -60.5125
0.0102          805.8579            36.95           -58.1252
0.0103          600.5212            43.26           -55.5706
0.0104          433.9397            53.37           -52.7486
0.0105          308.9268            70.87           -49.7971
0.0106          244.2780            99.49           -47.7577
0.0106          257.4648           130.96           -48.2144
0.0107          324.0369           152.10           -50.2119
0.0108          410.2649           164.16           -52.2613
0.0109          500.6140           171.37           -53.9901
0.0110          589.5430           176.04           -55.4103
0.0110          675.1055           179.29           -56.5874
0.0111          756.6646          -178.34           -57.5781
0.0112          834.0947          -176.53           -58.4243
0.0113          907.4871          -175.10           -59.1568
0.0114          977.0127          -173.95           -59.7980
0.0114         1042.8850          -172.99           -60.3647
0.0115         1105.3154          -172.19           -60.8697
0.0116         1164.5139          -171.51           -61.3229
0.0117         1220.6768          -170.92           -61.7320
0.0118         1273.9927          -170.41           -62.1033
0.0118         1324.6333          -169.95           -62.4419
0.0119         1372.7588          -169.55           -62.7519
0.0120         1418.5159          -169.19           -63.0367
0.0121         1462.0398          -168.87           -63.2992
0.0122         1503.4609          -168.57           -63.5418
0.0122         1542.8931          -168.31           -63.7667
0.0123         1580.4492          -168.06           -63.9756
0.0124         1616.2246          -167.84           -64.1700
0.0125         1650.3162          -167.63           -64.3513
0.0126         1682.8105          -167.44           -64.5207
0.0126         1713.7903          -167.26           -64.6791
0.0127         1743.3315          -167.10           -64.8276
0.0128         1771.5032          -166.94           -64.9668
0.0129         1798.3711          -166.80           -65.0976
0.0130         1824.0007          -166.66           -65.2205
0.0130         1848.4512          -166.53           -65.3362
0.0131         1871.7751          -166.41           -65.4451
0.0132         1894.0234          -166.30           -65.5477
0.0133         1915.2488          -166.19           -65.6445
0.0134         1935.4958          -166.09           -65.7358
0.0134         1954.8059          -165.99           -65.8221
0.0135         1973.2205          -165.90           -65.9035
0.0136         1990.7820          -165.81           -65.9805
0.0137         2007.5239          -165.73           -66.0532
0.0138         2023.4832          -165.65           -66.1220
0.0138         2038.6892          -165.57           -66.1870
0.0139         2053.1780          -165.50           -66.2485
0.0140         2066.9778          -165.43           -66.3067
```

DESCRIBING FUNCTION DATA

FREQUENCY = 56.610

ALPHA = 0.0055

B	N	PHASE	-1/N(DB)
0.0056	2811.1938	32.44	-68.9778
0.0056	2136.1204	36.08	-66.5925
0.0057	1634.1643	40.74	-64.2659
0.0057	1233.0056	47.36	-61.8193
0.0058	911.0759	57.52	-59.1911
0.0058	671.7336	74.02	-56.5439
0.0059	542.2371	99.22	-54.6838
0.0059	547.1372	127.39	-54.7619
0.0060	652.7476	148.35	-56.2949
0.0060	802.6943	161.28	-58.0910
0.0061	965.2810	169.32	-59.6931
0.0061	1127.5667	174.63	-61.0428
0.0062	1284.5220	178.34	-62.1748
0.0063	1434.2671	-178.93	-63.1326
0.0063	1576.2329	-176.85	-63.9524
0.0064	1710.4219	-175.20	-64.6620
0.0064	1837.0771	-173.87	-65.2825
0.0065	1956.5686	-172.78	-65.8299
0.0065	2069.2861	-171.85	-66.3164
0.0066	2175.6387	-171.07	-66.7517
0.0066	2276.0090	-170.39	-67.1435
0.0067	2370.7688	-169.80	-67.4978
0.0067	2460.2668	-169.27	-67.8196
0.0068	2544.8293	-168.81	-68.1132
0.0069	2624.7527	-168.40	-68.3818
0.0069	2700.3184	-168.02	-68.6283
0.0070	2771.7900	-167.69	-68.8552
0.0070	2839.3950	-167.38	-69.0645
0.0071	2903.3601	-167.10	-69.2580
0.0071	2963.9014	-166.84	-69.4373
0.0072	3021.2019	-166.60	-69.6036
0.0072	3075.4402	-166.38	-69.7581
0.0073	3126.7830	-166.18	-69.9019
0.0073	3175.3940	-165.99	-70.0359
0.0074	3221.4092	-165.81	-70.1609
0.0074	3264.9675	-165.64	-70.2776
0.0075	3305.1929	-165.49	-70.3866
0.0076	3345.2063	-165.34	-70.4884
0.0076	3382.1211	-165.20	-70.5838
0.0077	3417.0393	-165.07	-70.6730
0.0077	3450.0581	-164.95	-70.7565
0.0078	3481.2764	-164.83	-70.8348
0.0078	3510.7781	-164.72	-70.9081
0.0079	3538.6392	-164.61	-70.9767
0.0079	3564.9492	-164.51	-71.0411
0.0080	3589.7737	-164.42	-71.1013
0.0080	3613.1768	-164.33	-71.1578
0.0081	3635.2361	-164.24	-71.2106
0.0081	3656.0046	-164.16	-71.2601
0.0082	3675.5469	-164.08	-71.3064

```
          DESCRIBING FUNCTION DATA
          FREQUENCY = 62.000

          ALPHA = 0.0035

     B              N             PHASE          -1/N(DB)

  0.0035        4775.6094          35.54          -73.5806
  0.0036        3626.2739          39.57          -71.1892
  0.0036        2777.4131          44.70          -68.8728
  0.0037        2106.3257          51.87          -66.4705
  0.0037        1577.0222          62.62          -63.9568
  0.0038        1194.6785          79.28          -61.5450
  0.0038         996.3599         103.00          -59.9683
  0.0038        1004.8066         128.44          -60.0417
  0.0039        1165.1182         147.89          -61.3274
  0.0039        1396.2275         160.52          -62.8991
  0.0040        1649.6123         168.68          -64.3476
  0.0040        1903.7549         174.20          -65.5922
  0.0040        2149.7078         178.11          -66.6476
  0.0041        2383.9434        -178.98          -67.5459
  0.0041        2605.2627        -176.74          -68.3170
  0.0042        2813.5598        -174.96          -68.9851
  0.0042        3009.1775        -173.52          -69.5690
  0.0043        3192.7107        -172.32          -70.0832
  0.0043        3364.8289        -171.32          -70.5393
  0.0043        3526.2234        -170.46          -70.9462
  0.0044        3677.5554        -169.72          -71.3112
  0.0044        3819.4849        -169.07          -71.6401
  0.0045        3952.6213        -168.50          -71.9377
  0.0045        4077.5251        -167.99          -72.2079
  0.0045        4194.7266        -167.53          -72.4541
  0.0046        4304.7109        -167.12          -72.6789
  0.0046        4407.9453        -166.75          -72.8847
  0.0047        4504.8438        -166.41          -73.0736
  0.0047        4595.7930        -166.10          -73.2472
  0.0048        4681.1602        -165.82          -73.4071
  0.0048        4761.2773        -165.56          -73.5545
  0.0048        4836.4609        -165.31          -73.6905
  0.0049        4906.9883        -165.09          -73.8163
  0.0049        4973.1328        -164.88          -73.9326
  0.0050        5035.1602        -164.68          -74.0403
  0.0050        5093.2969        -164.50          -74.1400
  0.0050        5147.7500        -164.33          -74.2323
  0.0051        5198.7344        -164.17          -74.3179
  0.0051        5246.4414        -164.01          -74.3973
  0.0052        5291.0391        -163.87          -74.4708
  0.0052        5332.7109        -163.73          -74.5390
  0.0053        5371.5938        -163.60          -74.6021
  0.0053        5407.8516        -163.48          -74.6605
  0.0053        5441.6172        -163.36          -74.7146
  0.0054        5473.0156        -163.25          -74.7645
  0.0054        5502.1797        -163.15          -74.8107
  0.0055        5529.2188        -163.05          -74.8533
  0.0055        5554.2422        -162.95          -74.8925
  0.0056        5577.3398        -162.86          -74.9285
  0.0056        5598.6250        -162.77          -74.9616
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          DESCRIBING FUNCTION DATA
          FREQUENCY = 45.000

          ALPHA = 0.0100

    B              N              PHASE           -1/N(DB)

 0.0101        1233.4875           25.95          -61.8227
 0.0101         922.4802           29.06          -59.2991
 0.0102         689.1995           33.25          -56.7669
 0.0103         500.3091           39.63          -53.9848
 0.0103         346.5730           50.63          -50.7959
 0.0104         233.9463           71.83          -47.3823
 0.0105         190.4455          108.20          -45.5954
 0.0105         230.1004          141.57          -47.2383
 0.0106         310.6777          159.65          -49.8462
 0.0106         401.2224          169.15          -52.0677
 0.0107         491.7175          174.73          -53.8343
 0.0108         579.1682          178.35          -55.2561
 0.0108         662.6948         -179.12          -56.4263
 0.0109         742.1340         -177.26          -57.4096
 0.0110         817.5820         -175.84          -58.2506
 0.0110         889.2295         -174.71          -58.9803
 0.0111         957.2971         -173.79          -59.6209
 0.0112        1022.0098         -173.03          -60.1891
 0.0112        1083.5806         -172.39          -60.6972
 0.0113        1142.2085         -171.84          -61.1549
 0.0114        1198.0796         -171.37          -61.5697
 0.0114        1251.3662         -170.95          -61.9477
 0.0115        1302.2212         -170.59          -62.2937
 0.0116        1350.7869         -170.26          -62.6117
 0.0116        1397.1980         -169.97          -62.9052
 0.0117        1441.5750         -169.70          -63.1767
 0.0117        1484.0293         -169.46          -63.4288
 0.0118        1524.6650         -169.25          -63.6635
 0.0119        1563.5762         -169.05          -63.8824
 0.0119        1600.8506         -168.86          -64.0870
 0.0120        1636.5732         -168.69          -64.2787
 0.0121        1670.8147         -168.54          -64.4586
 0.0121        1703.6563         -168.39          -64.6276
 0.0122        1735.1553         -168.25          -64.7868
 0.0123        1765.3767         -168.13          -64.9368
 0.0123        1794.3813         -168.01          -65.0783
 0.0124        1822.2202         -167.90          -65.2120
 0.0125        1848.9495         -167.79          -65.3385
 0.0125        1874.6118         -167.69          -65.4582
 0.0126        1899.2578         -167.60          -65.5717
 0.0126        1922.9282         -167.51          -65.6793
 0.0127        1945.6631         -167.43          -65.7813
 0.0128        1967.5032         -167.35          -65.8783
 0.0128        1988.4817         -167.27          -65.9704
 0.0129        2008.6379         -167.20          -66.0580
 0.0130        2027.9993         -167.13          -66.1414
 0.0130        2046.5977         -167.06          -66.2206
 0.0131        2064.4663         -167.00          -66.2962
 0.0132        2081.6311         -166.94          -66.3681
 0.0132        2098.1150         -166.88          -66.4366
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DESCRIBING FUNCTION DATA
FREQUENCY = 50.150

ALPHA = 0.0065

     B              N           PHASE       -1/N(DB)

  0.0066       2121.3572        28.79       -66.5323
  0.0066       1603.3286        32.09       -64.1004
  0.0067       1215.9641        36.40       -61.6984
  0.0067        903.6431        42.70       -59.1199
  0.0068        650.0144        52.86       -56.2584
  0.0068        459.8135        70.66       -53.2516
  0.0069        363.3149       100.08       -51.2056
  0.0069        387.8416       132.02       -51.7731
  0.0070        493.0381       152.97       -53.8576
  0.0070        626.7251       164.77       -55.9415
  0.0071        765.8857       171.79       -57.6833
  0.0071        902.5076       176.33       -59.1090
  0.0072       1033.8213       179.48       -60.2889
  0.0072       1158.9558      -178.21       -61.2813
  0.0073       1277.7654      -176.45       -62.1290
  0.0073       1390.4126      -175.06       -62.8629
  0.0074       1497.1785      -173.94       -63.5054
  0.0074       1598.3855      -173.01       -64.0736
  0.0075       1694.3630      -172.23       -64.5801
  0.0075       1785.4329      -171.56       -65.0349
  0.0076       1871.8958      -170.99       -65.4456
  0.0076       1954.0325      -170.49       -65.8186
  0.0077       2032.1028      -170.05       -66.1589
  0.0077       2106.3528      -169.66       -66.4706
  0.0078       2177.0103      -169.31       -66.7572
  0.0078       2244.2700      -168.99       -67.0215
  0.0079       2308.3335      -168.70       -67.2660
  0.0079       2369.3716      -168.44       -67.4926
  0.0080       2427.5530      -168.20       -67.7034
  0.0080       2483.0288      -167.98       -67.8996
  0.0081       2535.9387      -167.78       -68.0828
  0.0081       2586.4155      -167.60       -68.2540
  0.0082       2634.5789      -167.42       -68.4142
  0.0082       2680.5549      -167.26       -68.5645
  0.0083       2724.4355      -167.11       -68.7055
  0.0083       2766.3323      -166.97       -68.8381
  0.0084       2806.3376      -166.84       -68.9628
  0.0084       2844.5381      -166.71       -69.0802
  0.0085       2881.0166      -166.59       -69.1909
  0.0085       2915.8535      -166.48       -69.2953
  0.0086       2949.1211      -166.38       -69.3938
  0.0086       2980.8892      -166.28       -69.4869
  0.0087       3011.2258      -166.18       -69.5748
  0.0087       3040.1951      -166.09       -69.6580
  0.0088       3067.8445      -166.01       -69.7367
  0.0088       3094.2417      -165.93       -69.8111
  0.0089       3119.4341      -165.85       -69.8815
  0.0089       3143.4761      -165.77       -69.9482
  0.0090       3166.4092      -165.70       -70.0113
  0.0090       3188.2827      -165.63       -70.0711
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          DESCRIBING FUNCTION DATA
          FREQUENCY  =  55.000

          ALPHA  =  0.0045

    B               N             PHASE          -1/N(DB)

0.0045          3347.0078          31.52         -70.4931
0.0046          2541.6218          35.07         -68.1022
0.0046          1941.8220          39.62         -65.7642
0.0047          1461.2092          46.12         -63.2942
0.0047          1074.0417          56.20         -60.6204
0.0048           784.7678          72.83         -57.8948
0.0048           628.5144          98.75         -55.9663
0.0048           638.3621         127.85         -56.1013
0.0049           771.3501         149.06         -57.7450
0.0049           956.6079         161.89         -59.6147
0.0050          1155.9346         169.77         -61.2587
0.0050          1354.2449         174.94         -62.6339
0.0050          1545.8279         178.54         -63.7832
0.0051          1728.6040        -178.82         -64.7539
0.0051          1901.9856        -176.80         -65.5841
0.0052          2066.0234        -175.21         -66.3027
0.0052          2221.0366        -173.92         -66.9311
0.0053          2367.4832        -172.86         -67.4857
0.0053          2505.8259        -171.97         -67.9790
0.0053          2636.5632        -171.21         -68.4207
0.0054          2760.1492        -170.56         -68.8186
0.0054          2877.0281        -169.99         -69.1789
0.0055          2987.6121        -169.48         -69.5065
0.0055          3092.2815        -169.03         -69.8056
0.0055          3191.3955        -168.63         -70.0796
0.0056          3285.2859        -168.27         -70.3315
0.0056          3374.2478        -167.95         -70.5635
0.0057          3456.5813        -167.65         -70.7779
0.0057          3538.5295        -167.38         -70.9764
0.0058          3614.3521        -167.13         -71.1606
0.0058          3686.2698        -166.90         -71.3317
0.0058          3754.4946        -166.69         -71.4910
0.0059          3819.2246        -166.49         -71.6395
0.0059          3880.6392        -166.31         -71.7781
0.0060          3938.9158        -166.14         -71.9075
0.0060          3994.2109        -165.98         -72.0286
0.0060          4046.6799        -165.83         -72.1420
0.0061          4096.4609        -165.69         -72.2482
0.0061          4143.6836        -165.55         -72.3477
0.0062          4188.4727        -165.43         -72.4411
0.0062          4230.9531        -165.31         -72.5288
0.0063          4271.2305        -165.19         -72.6111
0.0063          4309.3945        -165.09         -72.6883
0.0063          4345.5703        -164.98         -72.7609
0.0064          4379.8281        -164.89         -72.8291
0.0064          4412.2695        -164.80         -72.8932
0.0065          4442.9688        -164.71         -72.9535
0.0065          4472.0078        -164.62         -73.0100
0.0065          4499.4570        -164.54         -73.0632
0.0066          4525.3906        -164.46         -73.1131
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          DESCRIBING FUNCTION DATA
          FREQUENCY =  35.000

          ALPHA =  0.0100

    B              N             PHASE         -1/N(DB)

0.0100          923.5095          20.57        -59.3088
0.0101          657.7041          23.60        -56.3606
0.0101          457.7996          28.24        -53.2135
0.0102          296.1536          36.81        -49.4303
0.0102          170.5451          57.14        -44.6368
0.0103          118.4211         107.90        -41.4686
0.0103          175.1903         151.02        -44.8702
0.0104          267.0454         167.16        -48.5317
0.0104          361.1838         174.34        -51.1546
0.0105          451.8193         178.29        -53.0993
0.0105          537.9329        -179.23        -54.6146
0.0105          619.5305        -177.52        -55.8412
0.0106          696.8745        -176.28        -56.8631
0.0106          770.2817        -175.33        -57.7330
0.0107          840.0630        -174.57        -58.4862
0.0107          906.5017        -173.97        -59.1474
0.0108          969.8557        -173.46        -59.7341
0.0108         1030.3525        -173.04        -60.2597
0.0109         1088.1973        -172.68        -60.7341
0.0109         1143.5718        -172.36        -61.1653
0.0110         1196.6338        -172.09        -61.5592
0.0110         1247.5388        -171.84        -61.9211
0.0110         1296.4126        -171.63        -62.2549
0.0111         1343.3779        -171.43        -62.5639
0.0111         1388.5435        -171.26        -62.8512
0.0112         1432.0044        -171.10        -63.1189
0.0112         1473.8572        -170.95        -63.3691
0.0113         1514.1843        -170.82        -63.6036
0.0113         1553.0586        -170.70        -63.8237
0.0114         1590.5574        -170.59        -64.0310
0.0114         1626.7417        -170.48        -64.2264
0.0114         1661.6733        -170.39        -64.4109
0.0115         1695.4109        -170.30        -64.5855
0.0115         1728.0044        -170.21        -64.7509
0.0116         1759.5068        -170.13        -64.9078
0.0116         1789.9636        -170.06        -65.0569
0.0117         1819.4155        -169.99        -65.1986
0.0117         1847.9070        -169.92        -65.3336
0.0118         1875.4736        -169.86        -65.4622
0.0118         1902.1543        -169.80        -65.5849
0.0119         1927.9629        -169.74        -65.7021
0.0119         1952.9902        -169.69        -65.8140
0.0119         1977.2053        -169.64        -65.9210
0.0120         2000.6611        -169.59        -66.0235
0.0120         2023.3828        -169.54        -66.1216
0.0121         2045.3960        -169.50        -66.2155
0.0121         2066.7292        -169.46        -66.3057
0.0122         2087.4021        -169.42        -66.3921
0.0122         2107.4360        -169.38        -66.4751
0.0123         2126.8579        -169.34        -66.5548
```

```
DESCRIBING FUNCTION DATA
FREQUENCY = 39.177

ALPHA = 0.0089

    B           N          PHASE      -1/N(DB)

0.0089     1187.9441      22.79      -61.4959
0.0090      868.9451      25.80      -58.7798
0.0090      629.1567      30.09      -55.9752
0.0091      434.7249      37.20      -52.7643
0.0091      278.2578      51.26      -48.8889
0.0092      177.3013      83.21      -44.9742
0.0092      181.9892     130.27      -45.2009
0.0093      265.9189     156.81      -48.4950
0.0093      368.7612     168.57      -51.3349
0.0094      472.1443     174.70      -53.4815
0.0094      571.8198     178.40      -55.1452
0.0095      666.8135    -179.14      -56.4801
0.0095      757.0452    -177.39      -57.5824
0.0096      842.7185    -176.08      -58.5136
0.0096      924.1157    -175.06      -59.3145
0.0096     1001.5293    -174.24      -60.0133
0.0097     1075.2397    -173.57      -60.6301
0.0097     1145.5071    -173.01      -61.1800
0.0098     1212.5645    -172.53      -61.6741
0.0098     1276.6306    -172.12      -62.1213
0.0099     1337.8967    -171.77      -62.5285
0.0099     1396.5391    -171.45      -62.9010
0.0100     1452.7180    -171.17      -63.2436
0.0100     1506.5728    -170.93      -63.5598
0.0101     1558.2449    -170.70      -63.8527
0.0101     1607.8503    -170.50      -64.1249
0.0102     1655.5020    -170.32      -64.3785
0.0102     1701.3018    -170.15      -64.6156
0.0103     1745.3438    -170.00      -64.8376
0.0103     1787.7153    -169.85      -65.0460
0.0103     1828.4968    -169.72      -65.2419
0.0104     1867.7668    -169.60      -65.4264
0.0104     1905.5940    -169.49      -65.6006
0.0105     1942.0425    -169.38      -65.7652
0.0105     1977.1741    -169.28      -65.9209
0.0106     2011.0481    -169.19      -66.0685
0.0106     2043.7129    -169.10      -66.2084
0.0107     2075.2268    -169.02      -66.3413
0.0107     2105.6323    -168.94      -66.4676
0.0108     2134.9736    -168.87      -66.5879
0.0108     2163.2981    -168.80      -66.7023
0.0109     2190.6414    -168.73      -66.8114
0.0109     2217.0413    -168.67      -66.9155
0.0110     2242.5378    -168.61      -67.0148
0.0110     2267.1589    -168.55      -67.1096
0.0110     2290.9424    -168.50      -67.2003
0.0111     2313.9160    -168.45      -67.2869
0.0111     2336.1084    -168.40      -67.3699
0.0112     2357.5510    -168.35      -67.4492
0.0112     2378.2678    -168.30      -67.5252
```

```
          DESCRIBING FUNCTION DATA
          FREQUENCY = 45.000

          ALPHA = 0.0075

     B               N              PHASE          -1/N(DB)

  0.0075         1644.6440          25.95          -64.3214
  0.0076         1229.9536          29.06          -61.7978
  0.0076          918.9028          33.25          -59.2654
  0.0077          667.0461          39.62          -56.4831
  0.0077          462.0662          50.64          -53.2941
  0.0078          311.9058          71.84          -49.8805
  0.0078          253.9309         108.21          -48.0943
  0.0079          306.8291         141.58          -49.7379
  0.0079          414.2786         159.66          -52.3458
  0.0080          535.0110         169.16          -54.5673
  0.0080          655.6738         174.74          -56.3337
  0.0081          772.2756         178.35          -57.7554
  0.0081          883.6487        -179.12          -58.9256
  0.0082          989.5684        -177.26          -59.9089
  0.0082         1090.1665        -175.84          -60.7498
  0.0083         1185.6973        -174.71          -61.4795
  0.0083         1276.4556        -173.79          -62.1201
  0.0084         1362.7395        -173.03          -62.6882
  0.0084         1444.8337        -172.39          -63.1964
  0.0085         1523.0073        -171.84          -63.6540
  0.0085         1597.5042        -171.37          -64.0688
  0.0086         1668.5491        -170.95          -64.4468
  0.0086         1736.3530        -170.59          -64.7928
  0.0087         1801.1094        -170.26          -65.1108
  0.0087         1862.9915        -169.97          -65.4042
  0.0088         1922.1577        -169.70          -65.6758
  0.0088         1978.7661        -169.46          -65.9279
  0.0089         2032.9443        -169.25          -66.1625
  0.0089         2084.8264        -169.05          -66.3814
  0.0090         2134.5244        -168.86          -66.5860
  0.0090         2182.1536        -168.69          -66.7777
  0.0091         2227.8096        -168.54          -66.9576
  0.0091         2271.5955        -168.39          -67.1266
  0.0091         2313.5918        -168.25          -67.2857
  0.0092         2353.8892        -168.13          -67.4357
  0.0092         2392.5610        -168.01          -67.5773
  0.0093         2429.6802        -167.90          -67.7110
  0.0093         2465.3181        -167.79          -67.8375
  0.0094         2499.5369        -167.69          -67.9572
  0.0094         2532.3938        -167.60          -68.0706
  0.0095         2563.9534        -167.51          -68.1782
  0.0095         2594.2688        -167.43          -68.2803
  0.0096         2623.3877        -167.35          -68.3772
  0.0096         2651.3550        -167.27          -68.4693
  0.0097         2678.2290        -167.20          -68.5569
  0.0097         2704.0447        -167.13          -68.6403
  0.0098         2728.8430        -167.06          -68.7196
  0.0098         2752.6655        -167.00          -68.7951
  0.0099         2775.5508        -166.94          -68.8670
  0.0099         2797.5315        -166.88          -68.9355
```

APPENDIX B

Computer program for simulation of the system and numerical data.

```
*****-----*****-----*****-----*****-----*****-----*****-----

      C(1)=MAXIMUM VALUE OF INPUT SINE WAVE.
      C(2)=VALUE OF MOTOR ARMATURE INDUCTANCE.
      C(3)=VALUE OF MOTOR ARMATURE RESISTANCE.
      C(4)=VALUE OF MOMENT OF INERTIA.
      C(5)=REFERENCE VOLTAGE.
      C(6)=GAIN OF AMPLIFIER BEFORE DEAD ZONE.
      C(7)=MAGNITUDE OF DEAD ZONE.
      C(8)=GAIN OF AMPLIFIER AFTER DEAD ZONE.

*****-----*****-----*****-----*****-----*****-----*****-----

      DIMENSION X(30),XDOT(30),C(15)
      C(10)=1.
      IBP=1
      PI=3.141592
      X(10)=0.0
      X(8)=IBP
    1 CALL INTEG2(T,X,XDOT,C)
      X(9)=X(1)-97.0
      X(10)=T-2.9485
      XMAX=C(1)*SIN(PI/3.)
      THA=2.0*PI*60.0*T
      PHASEA=ABS(C(1)*SIN(THA))
      PHASEB=ABS(C(1)*SIN(THA+2.0*PI/3.))
      PHASEC=ABS(C(1)*SIN(THA+PI/3.))
      X(6)=AMAX1(PHASEA,PHASEB,PHASEC)
      IF(PHASEA.GE.XMAX)IPH=1
      IF(PHASEB.GE.XMAX)IPH=2
      IF(PHASEC.GE.XMAX)IPH=3
  206 ERROR=0.318*X(1)-C(5)
      X(8)=IPH
      VK1=C(6)*ERROR
      IF(VK1.GE.C(7)) VDZ=VK1-C(7)
      IF(VK1.LT.C(7)) VDZ=0.0
      IF(VK1.LT.0.0) VDZ=VK1
      VK2=VDZ*C(8)
      GO TO(100,101,102,103,104),IBP
  100 CONTINUE
      IF(VK2) 207,207,208
  207 IBP=1
      VIN=X(6)
      X(5)=VIN
      X(7)=0.
      X(3)=(1.0/C(2))*(VIN-0.95*X(1)-C(3)*X(2))
      XDOT(2)=X(3)
      IF(X(2).LT.-0.01) X(2)=-0.01
      X(4)=(1.0/C(4))*(0.95*X(2)-0.086*X(1))
      XDOT(1)=X(4)
      VLAST=VIN
      X(8)=IBP
      GO TO 1
  208 IF(VIN.LT.VLAST) GO TO 207
      GO TO(101,102,103),IPH
  101 VIN=PHASEA
      IF(VK2) 207,207,105
  105 CONTINUE
      X(7)=1.
      X(5)=VIN
      IF(VIN-.75)300,301,301
  300 VIN=0.0
      X(5)=VIN
      IBP=5
      GO TO 302
  301 IBP=2
  302 X(3)=(1.0/C(2))*(VIN-0.95*X(1)-C(3)*X(2))
      IF(X(2).LT.-0.01) X(3)=0.0
      XDOT(2)=X(3)
      IF(X(2).LT.-0.01) X(2)=-0.01
      X(4)=(1.0/C(4))*(0.95*X(2)-0.086*X(1))
      XDOT(1)=X(4)
```

```
    VLAST=VIN
    X(8)=IBP
    GO TO 1
102 VIN=PHASEB
    IF(VK2) 207,207,106
106 CONTINUE
    X(7)=2.
    X(5)=VIN
    IF(VIN-.75)303,304,304
303 VIN=0.0
    X(5)=VIN
    IBP=5
    GO TO 305
304 IBP=3
305 X(3)=(1.0/C(2))*(VIN-0.95*X(1)-C(3)*X(2))
    IF(X(2).LT.-0.01) X(3)=0.0
    XDOT(2)=X(3)
    IF(X(2).LT.-0.01) X(2)=-0.01
    X(4)=(1.0/C(4))*(0.95*X(2)-0.086*X(1))
    XDOT(1)=X(4)
    VLAST=VIN
    X(8)=IBP
    GO TO 1
103 VIN=PHASEC
    IF(VK2) 207,207,107
107 CONTINUE
    X(7)=3.
    X(5)=VIN
    IF(VIN-.75)306,307,307
306 VIN=0.0
    X(5)=VIN
    IBP=5
    GO TO 308
307 IBP=4
308 X(3)=(1.0/C(2))*(VIN-0.95*X(1)-C(3)*X(2))
    IF(X(2).LT.-0.01) X(3)=0.0
    XDOT(2)=X(3)
    IF(X(2).LT.-0.01) X(2)=-0.01
    X(4)=(1.0/C(4))*(0.95*X(2)-0.086*X(1))
    XDOT(1)=X(4)
    VLAST=VIN
    X(8)=IBP
    GO TO 1
104 VIN=0.0
    X(7)=4.
    X(5)=VIN
    X(3)=(1.0/C(2))*(VIN-0.95*X(1)-C(3)*X(2))
    IF(X(2).LT.-0.01) X(3)=0.0
    XDOT(2)=X(3)
    IF(X(2).LT.-0.01) X(2)=-0.01
    X(4)=(1.0/C(4))*(0.95*X(2)-0.086*X(1))
    XDOT(1)=X(4)
    IBP=5
    IF(VK2) 309,309,310
309 IBP=1
310 CONTINUE
    X(8)=IBP
    GO TO 1
    END
```

```
INPUT DATA RECORD


ORDER OF EQUATIONS =   2
INITIAL TIME       = 0.2948E 01
FINAL TIME         = 0.4000E 01
STEP SIZE          = 0.8000E-04

THE NON-ZERO CONSTANTS, C(I), ARE
               C( 1) = 0.1150E 03
               C( 2) = 0.8000E-02
               C( 3) = 0.5000E-01
               C( 4) = 0.1580E 01
               C( 5) = 0.3100E 02
               C( 6) = 0.1000E 02
               C( 8) = 0.1000E 02

THE NON-ZERO INITIAL CONDITIONS ARE
               X( 1) = 0.9750E 02
               X( 2) = -.1000E-01


THE COLUMN HEADINGS AND THE CORRESPONDING VARIABLES ARE

          TIME           X( 0)
          VIN            X( 5)
          VOUT           X( 1)
          IAR            X( 2)


THE INDIVIDUAL GRAPH TITLES AND THE CORRESPONDING VARIABLES

          OUTPUT VS TIME       X( 9) VS. X(10)
           INPUT VS TIME       X( 5) VS. X(10)
```

```
                    HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.39


    TIME              VIN                VOUT               IAR

0.29485E 01    0.11439E 03    0.97497E 02  -0.10000E-01
0.29501E 01    0.97632E 02    0.97499E 02   0.33633E 01
0.29517E 01    0.11439E 03    0.97482E 02   0.28235E 01
0.29532E 01    0.10614E 03    0.97478E 02   0.56874E 01
0.29548E 01    0.11144E 03    0.97476E 02   0.96778E 01
0.29564E 01    0.11269E 03    0.97478E 02   0.12314E 02
0.29580E 01    0.10611E 03    0.97484E 02   0.16117E 02
0.29595E 01    0.62842E 02    0.97492E 02   0.14752E 02
0.29612E 01    0.0            0.97493E 02   0.23400E 01
0.29627E 01    0.11451E 03    0.97483E 02   0.26836E 00

0.29643E 01    0.10759E 03    0.97475E 02   0.31946E 01
0.29659E 01    0.11175E 03    0.97471E 02   0.72116E 01
0.29675E 01    0.11243E 03    0.97471E 02   0.98642E 01
0.29691E 01    0.10659E 03    0.97474E 02   0.13750E 02
0.29707E 01    0.11475E 03    0.97480E 02   0.16537E 02
0.29722E 01    0.99150E 02    0.97491E 02   0.19769E 02
0.29738E 01    0.49255E 02    0.97502E 02   0.16292E 02
0.29754E 01    0.0            0.97503E 02   0.12784E 01
0.29770E 01    0.0            0.97493E 02  -0.10000E-01
0.29786E 01    0.11216E 03    0.97483E 02   0.34966E 00

0.29802E 01    0.10706E 03    0.97476E 02   0.43853E 01
0.29817E 01    0.11465E 03    0.97472E 02   0.72917E 01
0.29833E 01    0.99797E 02    0.97473E 02   0.10730E 02
0.29849E 01    0.11472E 03    0.97476E 02   0.14086E 02
0.29865E 01    0.10677E 03    0.97484E 02   0.16849E 02
0.29881E 01    0.11232E 03    0.97494E 02   0.20612E 02
0.29897E 01    0.79041E 02    0.97508E 02   0.21466E 02
0.29912E 01    0.15420E 02    0.97518E 02   0.12697E 02
0.29928E 01    0.0            0.97513E 02  -0.10000E-01
0.29944E 01    0.0            0.97504E 02  -0.10000E-01

0.29960E 01    0.0            0.97494E 02  -0.10000E-01
0.29976E 01    0.10629E 03    0.97484E 02  -0.10000E-01
0.29992E 01    0.11259E 03    0.97475E 02   0.37023E 01
0.30007E 01    0.11156E 03    0.97472E 02   0.64325E 01
0.30023E 01    0.10796E 03    0.97471E 02   0.10405E 02
0.30039E 01    0.11444E 03    0.97474E 02   0.13166E 02
0.30055E 01    0.10103E 03    0.97481E 02   0.16514E 02
0.30071E 01    0.11487E 03    0.97491E 02   0.19768E 02
0.30087E 01    0.91943E 02    0.97504E 02   0.22220E 02
0.30102E 01    0.37241E 02    0.97517E 02   0.16664E 02

0.30118E 01    0.0            0.97517E 02   0.87179E-01
0.30134E 01    0.0            0.97507E 02  -0.10000E-01
0.30150E 01    0.0            0.97498E 02  -0.10000E-01
0.30166E 01    0.0            0.97488E 02  -0.10000E-01
0.30182E 01    0.11492E 03    0.97479E 02   0.21703E 01
0.30197E 01    0.10530E 03    0.97473E 02   0.52198E 01
0.30213E 01    0.11308E 03    0.97471E 02   0.90968E 01
0.30229E 01    0.11041E 03    0.97473E 02   0.11751E 02
0.30245E 01    0.10883E 03    0.97478E 02   0.15660E 02
0.30261E 01    0.11416E 03    0.97486E 02   0.18239E 02
```

```
                 HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.39


   TIME           VIN            VOUT           IAR

0.30277E 01   0.10222E 03   0.97499E 02   0.21747E 02
0.30292E 01   0.54954E 02   0.97512E 02   0.19035E 02
0.30308E 01   0.0           0.97517E 02   0.50301E 01
0.30324E 01   0.0           0.97508E 02  -0.10000E-01
0.30340E 01   0.0           0.97498E 02  -0.10000E-01
0.30356E 01   0.0           0.97488E 02  -0.10000E-01
0.30372E 01   0.11400E 03   0.97479E 02   0.18241E 01
0.30387E 01   0.10281E 03   0.97473E 02   0.55891E 01
0.30403E 01   0.11496E 03   0.97471E 02   0.87767E 01
0.30419E 01   0.10423E 03   0.97473E 02   0.11796E 02

0.30435E 01   0.11352E 03   0.97478E 02   0.15507E 02
0.30451E 01   0.11022E 03   0.97487E 02   0.19078E 02
0.30467E 01   0.10982E 03   0.97499E 02   0.21894E 02
0.30482E 01   0.71112E 02   0.97514E 02   0.21640E 02
0.30498E 01   0.30413E 01   0.97523E 02   0.10995E 02
0.30514E 01   0.0           0.97517E 02  -0.10000E-01
0.30530E 01   0.0           0.97507E 02  -0.10000E-01
0.30545E 01   0.0           0.97497E 02  -0.10000E-01
0.30562E 01   0.0           0.97487E 02  -0.10000E-01
0.30577E 01   0.11000E 03   0.97479E 02   0.24432E 01

0.30593E 01   0.11364E 03   0.97473E 02   0.52389E 01
0.30608E 01   0.10392E 03   0.97471E 02   0.90283E 01
0.30625E 01   0.11500E 03   0.97472E 02   0.12077E 02
0.30641E 01   0.10313E 03   0.97478E 02   0.15122E 02
0.30656E 01   0.11350E 03   0.97486E 02   0.18709E 02
0.30672E 01   0.85234E 02   0.97498E 02   0.20397E 02
0.30688E 01   0.27156E 02   0.97508E 02   0.13184E 02
0.30704E 01   0.0           0.97504E 02  -0.10000E-01
0.30720E 01   0.0           0.97494E 02  -0.10000E-01
0.30736E 01   0.0           0.97485E 02  -0.10000E-01

0.30751E 01   0.10256E 03   0.97477E 02   0.30140E 01
0.30767E 01   0.11407E 03   0.97472E 02   0.67483E 01
0.30783E 01   0.10906E 03   0.97471E 02   0.95062E 01
0.30799E 01   0.11071E 03   0.97474E 02   0.13456E 02
0.30815E 01   0.11321E 03   0.97480E 02   0.16048E 02
0.30831E 01   0.10499E 03   0.97490E 02   0.19730E 02
0.30846E 01   0.60483E 02   0.97502E 02   0.17950E 02
0.30862E 01   0.0           0.97506E 02   0.49831E 01
0.30878E 01   0.0           0.97497E 02  -0.10000E-01
0.30894E 01   0.0           0.97487E 02  -0.10000E-01

0.30910E 01   0.11105E 03   0.97478E 02   0.29601E 01
0.30926E 01   0.11298E 03   0.97473E 02   0.57117E 01
0.30941E 01   0.10550E 03   0.97472E 02   0.95839E 01
0.30957E 01   0.11490E 03   0.97474E 02   0.12515E 02
0.30973E 01   0.10138E 03   0.97480E 02   0.15699E 02
0.30989E 01   0.11437E 03   0.97489E 02   0.19140E 02
0.31005E 01   0.87505E 02   0.97502E 02   0.21127E 02
0.31021E 01   0.30903E 02   0.97512E 02   0.14538E 02
0.31036E 01   0.0           0.97510E 02  -0.10000E-01
0.31052E 01   0.0           0.97500E 02  -0.10000E-01
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                    HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.39


   TIME              VIN               VOUT              IAR

0.31068E 01   0.0               0.97490E 02 -0.10000E-01
0.31084E 01   0.10673E 03       0.97481E 02  0.51490E 00
0.31100E 01   0.11449E 03       0.97473E 02  0.41493E 01
0.31116E 01   0.10779E 03       0.97470E 02  0.70121E 01
0.31131E 01   0.11169E 03       0.97470E 02  0.10972E 02
0.31147E 01   0.11246E 03       0.97473E 02  0.13534E 02
0.31163E 01   0.10856E 03       0.97480E 02  0.17386E 02
0.31179E 01   0.11477E 03       0.97491E 02  0.20119E 02
0.31195E 01   0.99027E 02       0.97505E 02  0.23280E 02
0.31211E 01   0.49036E 02       0.97520E 02  0.19660E 02

0.31226E 01   0.17837E 02       0.97524E 02  0.50718E 01
0.31242E 01   0.73649E 02       0.97516E 02 -0.10000E-01
0.31258E 01   0.11221E 03       0.97506E 02 -0.10000E-01
0.31274E 01   0.10697E 03       0.97496E 02 -0.10000E-01
0.31290E 01   0.64741E 02       0.97486E 02 -0.10000E-01
0.31305E 01   0.99562E 02       0.97478E 02  0.25301E 01
0.31321E 01   0.11470E 03       0.97472E 02  0.60265E 01
0.31337E 01   0.10655E 03       0.97471E 02  0.89137E 01
0.31353E 01   0.11227E 03       0.97473E 02  0.12809E 02
0.31369E 01   0.11152E 03       0.97479E 02  0.15392E 02

0.31385E 01   0.10743E 03       0.97488E 02  0.19202E 02
0.31401E 01   0.55780E 02       0.97500E 02  0.18224E 02
0.31416E 01   0.14106E 01       0.97504E 02  0.64137E 01
0.31432E 01   0.0               0.97496E 02 -0.10000E-01
0.31448E 01   0.0               0.97486E 02 -0.10000E-01
0.31464E 01   0.11253E 03       0.97477E 02  0.25888E 01
0.31480E 01   0.11162E 03       0.97472E 02  0.57275E 01
0.31496E 01   0.10738E 03       0.97471E 02  0.97031E 01
0.31511E 01   0.11446E 03       0.97473E 02  0.12465E 02
0.31527E 01   0.10091E 03       0.97479E 02  0.15934E 02

0.31543E 01   0.11486E 03       0.97488E 02  0.19111E 02
0.31559E 01   0.41780E 02       0.97501E 02  0.21556E 02
0.31575E 01   0.36959E 02       0.97513E 02  0.15986E 02
0.31591E 01   0.0               0.97512E 02 -0.10000E-01
0.31606E 01   0.0               0.97503E 02 -0.10000E-01
0.31622E 01   0.0               0.97493E 02 -0.10000E-01
0.31638E 01   0.10151E 03       0.97483E 02  0.10871E 00
0.31654E 01   0.11491E 03       0.97479E 02  0.34661E 01
0.31670E 01   0.10539E 03       0.97471E 02  0.65089E 01
0.31686E 01   0.11304E 03       0.97470E 02  0.10371E 02

0.31701E 01   0.11098E 03       0.97473E 02  0.13005E 02
0.31717E 01   0.10573E 03       0.97480E 02  0.16892E 02
0.31733E 01   0.11419E 03       0.97490E 02  0.19505E 02
0.31749E 01   0.10211E 03       0.97504E 02  0.22934E 02
0.31765E 01   0.54741E 02       0.97519E 02  0.20219E 02
0.31780E 01   0.0               0.97524E 02  0.61070E 01
0.31796E 01   0.0               0.97515E 02 -0.10000E-01
0.31812E 01   0.0               0.97506E 02 -0.10000E-01
0.31828E 01   0.0               0.97495E 02 -0.10000E-01
0.31844E 01   0.0               0.97486E 02 -0.10000E-01
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                HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.39


   TIME           VIN            VOUT           IAR

0.31860E 01   0.10270E 03   0.97478E 02   0.27896E 01
0.31875E 01   0.11490E 03   0.97472E 02   0.60315E 01
0.31891E 01   0.10435E 03   0.97471E 02   0.90870E 01
0.31907E 01   0.11548E 03   0.97473E 02   0.12846E 02
0.31923E 01   0.11025E 03   0.97479E 02   0.15459E 02
0.31939E 01   0.10954E 03   0.97438E 02   0.19318E 02
0.31955E 01   0.70921E 02   0.97500E 02   0.19030E 02
0.31970E 01   0.77954E 01   0.97507E 02   0.84337E 01
0.31986E 01   0.55043E 02   0.97499E 02  -0.10000E-01
0.32002E 01   0.10350E 03   0.97489E 02  -0.10000E-01

0.32018E 01   0.11563E 03   0.97480E 02   0.20730E 01
0.32034E 01   0.10991E 03   0.97474E 02   0.48678E 01
0.32050E 01   0.10952E 03   0.97472E 02   0.88980E 01
0.32066E 01   0.11367E 03   0.97473E 02   0.11588E 02
0.32081E 01   0.10362E 03   0.97478E 02   0.15269E 02
0.32097E 01   0.11500E 03   0.97486E 02   0.18224E 02
0.32113E 01   0.95489E 02   0.97498E 02   0.21077E 02
0.32129E 01   0.42954E 02   0.97510E 02   0.16509E 02
0.32145E 01   0.0           0.97511E 02   0.62462E 00
0.32160E 01   0.0           0.97501E 02  -0.10000E-01

0.32176E 01   0.0           0.97491E 02  -0.10000E-01
0.32192E 01   0.10436E 03   0.97482E 02   0.68982E 00
0.32208E 01   0.11455E 03   0.97474E 02   0.38373E 01
0.32224E 01   0.10207E 03   0.97470E 02   0.70550E 01
0.32240E 01   0.11403E 03   0.97470E 02   0.10734E 02
0.32255E 01   0.10915E 03   0.97474E 02   0.13425E 02
0.32271E 01   0.11054E 03   0.97481E 02   0.17313E 02
0.32287E 01   0.73900E 02   0.97491E 02   0.17526E 02
0.32303E 01   0.11599E 02   0.97495E 02   0.76003E 01
0.32319E 01   0.0           0.97488E 02  -0.10000E-01

0.32335E 01   0.10210E 03   0.97479E 02   0.17131E 01
0.32350E 01   0.11419E 03   0.97472E 02   0.54331E 01
0.32366E 01   0.10573E 03   0.97470E 02   0.32252E 01
0.32382E 01   0.11098E 03   0.97472E 02   0.12191E 02
0.32398E 01   0.11303E 03   0.97477E 02   0.14797E 02
0.32414E 01   0.10540E 03   0.97485E 02   0.18523E 02
0.32430E 01   0.61348E 02   0.97496E 02   0.16895E 02
0.32445E 01   0.0           0.97499E 02   0.41279E 01
0.32461E 01   0.0           0.97489E 02  -0.10000E-01
0.32477E 01   0.10830E 03   0.97480E 02   0.98985E 00

0.32493E 01   0.11132E 03   0.97473E 02   0.50592E 01
0.32509E 01   0.11279E 03   0.97470E 02   0.77728E 01
0.32525E 01   0.10590E 03   0.97471E 02   0.11639E 02
0.32540E 01   0.11486E 03   0.97475E 02   0.14505E 02
0.32556E 01   0.10090E 03   0.97484E 02   0.17698E 02
0.32572E 01   0.11447E 03   0.97495E 02   0.21057E 02
0.32588E 01   0.88460E 02   0.97510E 02   0.23100E 02
0.32604E 01   0.31884E 02   0.97523E 02   0.16645E 02
0.32620E 01   0.0           0.97522E 02  -0.10000E-01
0.32635E 01   0.0           0.97513E 02  -0.10000E-01
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                                   HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.39


     TIME              VIN                 VOUT              IAR

 0.32651E 01   0.0                 0.97503E 02 -0.10000E-01
 0.32667E 01   0.0                 0.97493E 02 -0.10000E-01
 0.32683E 01   0.11456E 03         0.97483E 02  0.39599E 00
 0.32699E 01   0.10773E 03         0.97476E 02  0.33376E 01
 0.32715E 01   0.11193E 03         0.97472E 02  0.73430E 01
 0.32730E 01   0.11225E 03         0.97471E 02  0.10012E 02
 0.32746E 01   0.10688E 03         0.97475E 02  0.13338E 02
 0.32762E 01   0.11470E 03         0.97482E 02  0.16656E 02
 0.32778E 01   0.97541E 02         0.97492E 02  0.19920E 02
 0.32794E 01   0.47956E 02         0.97503E 02  0.16502E 02

 0.32810E 01   0.0                 0.97504E 02  0.16445E 01
 0.32825E 01   0.0                 0.97495E 02 -0.10000E-01
 0.32841E 01   0.0                 0.97455E 02 -0.10000E-01
 0.32857E 01   0.10734E 03         0.97477E 02  0.37034E 01
 0.32873E 01   0.11450E 03         0.97473E 02  0.66052E 01
 0.32889E 01   0.10017E 03         0.97472E 02  0.10086E 02
 0.32904E 01   0.11477E 03         0.97475E 02  0.13419E 02
 0.32920E 01   0.10643E 03         0.97482E 02  0.16210E 02
 0.32936E 01   0.11246E 03         0.97492E 02  0.19970E 02
 0.32952E 01   0.79603E 02         0.97505E 02  0.20910E 02

 0.32968E 01   0.15166E 02         0.97514E 02  0.12286E 02
 0.32984E 01   0.0                 0.97509E 02 -0.10000E-01
 0.32999E 01   0.0                 0.97500E 02 -0.10000E-01
 0.33015E 01   0.0                 0.97490E 02 -0.10000E-01
 0.33031E 01   0.10600E 03         0.97480E 02  0.61872E 00
```

```
INPUT DATA RECORD


ORDER OF EQUATIONS =  2
INITIAL TIME       = 0.2594E 01
FINAL TIME         = 0.3500E 01
STEP SIZE          = 0.8000E-04

THE NON-ZERO CONSTANTS, C(I), ARE
              C( 1) = 0.1150E 03
              C( 2) = 0.8000E-02
              C( 3) = 0.8000E-01
              C( 4) = 0.1380E 01
              C( 5) = 0.2280E 02
              C( 6) = 0.1000E 02
              C( 8) = 0.1000E 02

THE NON-ZERO INITIAL CONDITIONS ARE
              X( 1) = 0.1031E 03
              X( 2) = 0.1424E 02


THE COLUMN HEADINGS AND THE CORRESPONDING VARIABLES ARE

       TIME          X( 0)
       VIN           X( 5)
       VOUT          X( 1)
       IAR           X( 2)


THE INDIVIDUAL GRAPH TITLES AND THE CORRESPONDING VARIABLES

       OUTPUT VS TIME       X( 9) VS. X(10)
        INPUT VS TIME       X( 5) VS. X(10)
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                HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.59


     TIME             VIN              VOUT             IAR

 0.25939E 01    0.10927E 03    0.10313E 03    0.14242E 02
 0.25955E 01    0.11398E 03    0.10314E 03    0.15309E 02
 0.25971E 01    0.10287E 03    0.10314E 03    0.18289E 02
 0.25986E 01    0.55181E 02    0.10315E 03    0.14810E 02
 0.26002E 01    0.0            0.10315E 03   -0.99193E-02
 0.26018E 01    0.11354E 03    0.10314E 03    0.41007E 00
 0.26034E 01    0.11017E 03    0.10313E 03    0.21569E 01
 0.26050E 01    0.10966E 03    0.10313E 03    0.51631E 01
 0.26065E 01    0.11360E 03    0.10312E 03    0.68384E 01
 0.26081E 01    0.10344E 03    0.10312E 03    0.95243E 01

 0.26097E 01    0.11506E 03    0.10312E 03    0.11536E 02
 0.26113E 01    0.10355E 03    0.10313E 03    0.13491E 02
 0.26129E 01    0.11373E 03    0.10313E 03    0.16069E 02
 0.26145E 01    0.10579E 03    0.10314E 03    0.17579E 02
 0.26161E 01    0.11064E 03    0.10315E 03    0.20338E 02
 0.26176E 01    0.72251E 02    0.10316E 03    0.19202E 02
 0.26192E 01    0.94651E 01    0.10317E 03    0.77931E 01
 0.26208E 01    0.55570E 02    0.10316E 03   -0.10000E-01
 0.26224E 01    0.10367E 03    0.10315E 03   -0.10000E-01
 0.26240E 01    0.11392E 03    0.10314E 03    0.18427E 01

 0.26256E 01    0.10941E 03    0.10313E 03    0.35957E 01
 0.26271E 01    0.11040E 03    0.10313E 03    0.65778E 01
 0.26287E 01    0.11341E 03    0.10312E 03    0.82245E 01
 0.26303E 01    0.10452E 03    0.10312E 03    0.10939E 02
 0.26319E 01    0.11498E 03    0.10313E 03    0.12847E 02
 0.26335E 01    0.10250E 03    0.10313E 03    0.14870E 02
 0.26351E 01    0.11409E 03    0.10314E 03    0.17344E 02
 0.26366E 01    0.86227E 02    0.10315E 03    0.18104E 02
 0.26382E 01    0.26545E 02    0.10315E 03    0.10099E 02
 0.26398E 01    0.0            0.10315E 03   -0.10000E-01

 0.26414E 01    0.10505E 03    0.10314E 03    0.18060E 01
 0.26430E 01    0.11494E 03    0.10313E 03    0.38182E 01
 0.26446E 01    0.10142E 03    0.10313E 03    0.60311E 01
 0.26461E 01    0.11424E 03    0.10312E 03    0.86041E 01
 0.26477E 01    0.10660E 03    0.10312E 03    0.10288E 02
 0.26493E 01    0.11109E 03    0.10313E 03    0.13152E 02
 0.26509E 01    0.11299E 03    0.10313E 03    0.14675E 02
 0.26525E 01    0.10557E 03    0.10314E 03    0.17346E 02
 0.26541E 01    0.11490E 03    0.10315E 03    0.19076E 02
 0.26556E 01    0.97763E 02    0.10316E 03    0.21073E 02

 0.26572E 01    0.46842E 02    0.10317E 03    0.16069E 02
 0.26588E 01    0.0            0.10317E 03   -0.10000E-01
 0.26604E 01    0.0            0.10316E 03   -0.10000E-01
 0.26620E 01    0.0            0.10315E 03   -0.10000E-01
 0.26636E 01    0.10606E 03    0.10314E 03    0.13862E 01
 0.26651E 01    0.11464E 03    0.10313E 03    0.33369E 01
 0.26667E 01    0.10670E 03    0.10313E 03    0.56586E 01
 0.26683E 01    0.11450E 03    0.10312E 03    0.81412E 01
 0.26699E 01    0.10774E 03    0.10312E 03    0.98779E 01
 0.26715E 01    0.11172E 03    0.10312E 03    0.12725E 02
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 HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.59


   TIME           VIN            VOUT           IAR

0.26731E 01   0.11245E 03   0.10313E 03   0.14243E 02
0.26746E 01   0.10655E 03   0.10314E 03   0.16971E 02
0.26762E 01   0.11476E 03   0.10314E 03   0.18542E 02
0.26778E 01   0.99097E 02   0.10316E 03   0.20768E 02
0.26794E 01   0.49161E 02   0.10317E 03   0.16143E 02
0.26810E 01   0.0           0.10317E 03   0.98521E-01
0.26826E 01   0.0           0.10316E 03  -0.10000E-01
0.26841E 01   0.0           0.10315E 03  -0.10000E-01
0.26857E 01   0.10702E 03   0.10314E 03   0.22936E 01
0.26873E 01   0.11467E 03   0.10313E 03   0.41701E 01

0.26889E 01   0.99731E 02   0.10312E 03   0.65965E 01
0.26905E 01   0.11471E 03   0.10312E 03   0.89477E 01
0.26921E 01   0.10681E 03   0.10312E 03   0.10727E 02
0.26936E 01   0.11230E 03   0.10313E 03   0.13525E 02
0.26952E 01   0.11139E 03   0.10313E 03   0.15031E 02
0.26968E 01   0.10748E 03   0.10314E 03   0.17783E 02
0.26984E 01   0.11457E 03   0.10315E 03   0.19383E 02
0.27000E 01   0.10037E 03   0.10316E 03   0.21507E 02
0.27016E 01   0.51461E 02   0.10317E 03   0.17334E 02
0.27031E 01   0.0           0.10317E 03   0.16334E 01

0.27047E 01   0.0           0.10316E 03  -0.10000E-01
0.27063E 01   0.0           0.10315E 03  -0.10000E-01
0.27079E 01   0.10793E 03   0.10314E 03   0.12404E 00
0.27095E 01   0.11495E 03   0.10313E 03   0.19812E 01
0.27110E 01   0.10095E 03   0.10313E 03   0.45373E 01
0.27126E 01   0.11486E 03   0.10312E 03   0.68256E 01
0.27142E 01   0.10584E 03   0.10312E 03   0.86994E 01
0.27158E 01   0.11282E 03   0.10312E 03   0.11485E 02
0.27174E 01   0.11127E 03   0.10312E 03   0.13031E 02
0.27190E 01   0.10836E 03   0.10313E 03   0.15844E 02

0.27205E 01   0.11432E 03   0.10314E 03   0.17429E 02
0.27221E 01   0.10156E 03   0.10315E 03   0.15786E 02
0.27237E 01   0.53725E 02   0.10316E 03   0.15998E 02
0.27253E 01   0.0           0.10316E 03   0.51559E 00
0.27269E 01   0.0           0.10315E 03  -0.10000E-01
0.27285E 01   0.11094E 03   0.10314E 03   0.78560E 00
0.27300E 01   0.10676E 03   0.10313E 03   0.38016E 01
0.27316E 01   0.11417E 03   0.10312E 03   0.55558E 01
0.27332E 01   0.10219E 03   0.10312E 03   0.81511E 01
0.27348E 01   0.11496E 03   0.10312E 03   0.10283E 02

0.27364E 01   0.10482E 03   0.10312E 03   0.12173E 02
0.27380E 01   0.11329E 03   0.10313E 03   0.14847E 02
0.27395E 01   0.11000E 03   0.10313E 03   0.16352E 02
0.27411E 01   0.10919E 03   0.10314E 03   0.19126E 02
0.27427E 01   0.70033E 02   0.10315E 03   0.17699E 02
0.27443E 01   0.65772E 01   0.10316E 03   0.58037E 01
0.27459E 01   0.0           0.10315E 03  -0.10000E-01
0.27475E 01   0.10428E 03   0.10314E 03   0.63493E 00
0.27490E 01   0.11350E 03   0.10313E 03   0.34574E 01
0.27506E 01   0.11025E 03   0.10312E 03   0.51556E 01
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            HASAN KUCADGLU.SPEED CONTROL OF A DC.MOTOR.NO.59


   TIME            VIN             VOUT            IAR

0.27522E 01   0.10958E 03   0.10312E 03   0.61151E 01
0.27538E 01   0.11384E 03   0.10312E 03   0.97685E 01
0.27554E 01   0.10332E 03   0.10312E 03   0.12380E 02
0.27570E 01   0.11500E 03   0.10313E 03   0.14354E 02
0.27585E 01   0.10374E 03   0.10313E 03   0.16257E 02
0.27601E 01   0.11370E 03   0.10314E 03   0.18795E 02
0.27617E 01   0.54353E 02   0.10315E 03   0.19300E 02
0.27633E 01   0.25629E 02   0.10316E 03   0.10803E 02
0.27649E 01   0.0           0.10315E 03  -0.10000E-01
0.27665E 01   0.10386E 03   0.10314E 03  -0.10000E-01

0.27680E 01   0.11500E 03   0.10313E 03   0.20634E 01
0.27696E 01   0.10319E 03   0.10313E 03   0.42040E 01
0.27712E 01   0.11368E 03   0.10312E 03   0.68989E 01
0.27728E 01   0.10948E 03   0.10312E 03   0.85703E 01
0.27744E 01   0.11033E 03   0.10312E 03   0.11476E 02
0.27760E 01   0.11345E 03   0.10312E 03   0.13047E 02
0.27775E 01   0.10441E 03   0.10313E 03   0.15679E 02
0.27791E 01   0.11495E 03   0.10314E 03   0.17518E 02
0.27807E 01   0.96253E 02   0.10315E 03   0.19396E 02
0.27823E 01   0.44276E 02   0.10316E 03   0.14003E 02

0.27839E 01   0.23039E 02   0.10315E 03  -0.10000E-01
0.27855E 01   0.11058E 03   0.10314E 03   0.29790E 00
0.27870E 01   0.11323E 03   0.10313E 03   0.20333E 01
0.27886E 01   0.10454E 03   0.10313E 03   0.48765E 01
0.27902E 01   0.11493E 03   0.10312E 03   0.68431E 01
0.27918E 01   0.10203E 03   0.10312E 03   0.89994E 01
0.27934E 01   0.11421E 03   0.10312E 03   0.11534E 02
0.27950E 01   0.10858E 03   0.10313E 03   0.13168E 02
0.27965E 01   0.11102E 03   0.10313E 03   0.15988E 02
0.27981E 01   0.11300E 03   0.10314E 03   0.17465E 02

0.27997E 01   0.10546E 03   0.10315E 03   0.20084E 02
0.28013E 01   0.61465E 02   0.10316E 03   0.17382E 02
0.28029E 01   0.0           0.10316E 03   0.35548E 01
0.28045E 01   0.0           0.10315E 03  -0.10000E-01
0.28060E 01   0.10826E 03   0.10314E 03   0.15162E 00
0.28076E 01   0.11135E 03   0.10313E 03   0.31660E 01
0.28092E 01   0.11276E 03   0.10313E 03   0.48425E 01
0.28108E 01   0.10597E 03   0.10312E 03   0.76922E 01
0.28124E 01   0.11485E 03   0.10312E 03   0.95526E 01
0.28140E 01   0.10082E 03   0.10312E 03   0.11766E 02

0.28155E 01   0.11446E 03   0.10313E 03   0.14161E 02
0.28171E 01   0.10762E 03   0.10313E 03   0.15796E 02
0.28187E 01   0.11166E 03   0.10314E 03   0.18549E 02
0.28203E 01   0.76890E 02   0.10315E 03   0.18086E 02
0.28219E 01   0.15552E 02   0.10316E 03   0.77945E 01
0.28234E 01   0.0           0.10315E 03  -0.10000E-01
0.28250E 01   0.10021E 03   0.10314E 03   0.75112E 00
0.28266E 01   0.11459E 03   0.10313E 03   0.32682E 01
0.28282E 01   0.10737E 03   0.10313E 03   0.51027E 01
0.28298E 01   0.11196E 03   0.10312E 03   0.80134E 01
```

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                 HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.59


    TIME              VIN              VOUT             IAR


0.28314E 01    0.11223E 03    0.10312E 03    0.96071E 01
0.28329E 01    0.10693E 03    0.10312E 03    0.12427E 02
0.28345E 01    0.11409E 03    0.10313E 03    0.14150E 02
0.28361E 01    0.99610E 02    0.10313E 03    0.16397E 02
0.28377E 01    0.11459E 03    0.10314E 03    0.18611E 02
0.28393E 01    0.90155E 02    0.10315E 03    0.19515E 02
0.28409E 01    0.34434E 02    0.10316E 03    0.12783E 02
0.28424E 01    0.0            0.10316E 03   -0.10000E-01
0.28440E 01    0.0            0.10315E 03   -0.10000E-01
0.28456E 01    0.11459E 03    0.10314E 03    0.15806E 01

0.28472E 01    0.10024E 03    0.10313E 03    0.40804E 01
0.28488E 01    0.11478E 03    0.10312E 03    0.64356E 01
0.28504E 01    0.10643E 03    0.10312E 03    0.82774E 01
0.28519E 01    0.11251E 03    0.10312E 03    0.11099E 02
0.28535E 01    0.11155E 03    0.10313E 03    0.12544E 02
0.28551E 01    0.10784E 03    0.10313E 03    0.15448E 02
0.28567E 01    0.11447E 03    0.10314E 03    0.17067E 02
0.28583E 01    0.10056E 03    0.10315E 03    0.19371E 02
0.28599E 01    0.52390E 02    0.10316E 03    0.15280E 02
0.28614E 01    0.0            0.10316E 03   -0.10000E-01

0.28630E 01    0.0            0.10315E 03   -0.10000E-01
0.28646E 01    0.11133E 03    0.10314E 03    0.13863E 01
0.28662E 01    0.10620E 03    0.10313E 03    0.43814E 01
0.28678E 01    0.11434E 03    0.10312E 03    0.61543E 01
0.28694E 01    0.10146E 03    0.10312E 03    0.86845E 01
0.28709E 01    0.11491E 03    0.10312E 03    0.10857E 02
0.28725E 01    0.10543E 03    0.10312E 03    0.12704E 02
0.28741E 01    0.11302E 03    0.10313E 03    0.15404E 02
0.28757E 01    0.11151E 03    0.10314E 03    0.16390E 02
0.28773E 01    0.10870E 03    0.10315E 03    0.19647E 02

0.28789E 01    0.53811E 02    0.10316E 03    0.18035E 02
0.28804E 01    0.51137E 01    0.10315E 03    0.58505E 01
0.28820E 01    0.0            0.10315E 03   -0.10000E-01
0.28836E 01    0.10492E 03    0.10314E 03   -0.10000E-01
0.28852E 01    0.11324E 03    0.10313E 03    0.25752E 01
0.28868E 01    0.11667E 03    0.10313E 03    0.42740E 01
0.28884E 01    0.10911E 03    0.10312E 03    0.72420E 01
0.28899E 01    0.11404E 03    0.10312E 03    0.89289E 01
0.28915E 01    0.10265E 03    0.10312E 03    0.11505E 02
0.28931E 01    0.11498E 03    0.10312E 03    0.13548E 02

0.28947E 01    0.10439E 03    0.10313E 03    0.15416E 02
0.28963E 01    0.11345E 03    0.10314E 03    0.18011E 02
0.28979E 01    0.11031E 03    0.10315E 03    0.19471E 02
0.28994E 01    0.10951E 03    0.10316E 03    0.22197E 02
0.29010E 01    0.70839E 02    0.10317E 03    0.20832E 02
0.29026E 01    0.75945E 01    0.10318E 03    0.90695E 01
0.29042E 01    0.53133E 02    0.10317E 03   -0.10000E-01
0.29058E 01    0.10334E 03    0.10316E 03   -0.10000E-01
0.29074E 01    0.11366E 03    0.10315E 03   -0.10000E-01
0.29089E 01    0.10994E 03    0.10314E 03   -0.10000E-01
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                    HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.59


     TIME             VIN               VOUT              IAR

  0.29105E 01    0.10939E 03    0.10313E 03    0.30202E 01
  0.29121E 01    0.11369E 03    0.10313E 03    0.47390E 01
  0.29137E 01    0.10375E 03    0.10312E 03    0.74597E 01
  0.29153E 01    0.11540E 03    0.10312E 03    0.94781E 01
  0.29169E 01    0.10329E 03    0.10312E 03    0.11494E 02
  0.29184E 01    0.11385E 03    0.10313E 03    0.14080E 02
  0.29200E 01    0.10957E 03    0.10313E 03    0.15633E 02
  0.29216E 01    0.11025E 03    0.10314E 03    0.16424E 02
  0.29232E 01    0.72832E 02    0.10315E 03    0.17402E 02
  0.29248E 01    0.10212E 02    0.10316E 03    0.61592E 01

  0.29264E 01    0.0            0.10315E 03   -0.10000E-01
  0.29279E 01    0.10273E 03    0.10314E 03    0.14697E 01
  0.29295E 01    0.11402E 03    0.10313E 03    0.41741E 01
  0.29311E 01    0.10917E 03    0.10312E 03    0.59010E 01
  0.29327E 01    0.11051E 03    0.10312E 03    0.88448E 01
  0.29343E 01    0.11325E 03    0.10312E 03    0.10450E 02
  0.29358E 01    0.10484E 03    0.10313E 03    0.13149E 02
  0.29374E 01    0.11496E 03    0.10313E 03    0.14998E 02
  0.29390E 01    0.10215E 03    0.10314E 03    0.17012E 02
  0.29406E 01    0.11418E 03    0.10315E 03    0.19425E 02

  0.29422E 01    0.86739E 02    0.10316E 03    0.20213E 02
  0.29438E 01    0.29296E 02    0.10317E 03    0.12300E 02
  0.29453E 01    0.0            0.10316E 03   -0.10000E-01
  0.29469E 01    0.0            0.10315E 03   -0.10000E-01
  0.29485E 01    0.11492E 03    0.10314E 03    0.96490E 00
```

```
INPUT DATA RECORD


ORDER OF EQUATIONS =   2
INITIAL TIME       = 0.2594E 01
FINAL TIME         = 0.3500E 01
STEP SIZE          = 0.8000E-04

THE NON-ZERO CONSTANTS, C(I), ARE
                C( 1) = 0.1150E 03
                C( 2) = 0.3000E-02
                C( 3) = 0.8000E-01
                C( 4) = 0.1380E 01
                C( 5) = 0.3350E 02
                C( 6) = 0.1000E 02
                C( 8) = 0.1000E 02

THE NON-ZERO INITIAL CONDITIONS ARE
                X( 1) = 0.1053E 03
                X( 2) = 0.7794E 00


THE COLUMN HEADINGS AND THE CORRESPONDING VARIABLES ARE

         TIME          X( 0)
         VIN           X( 5)
         VOUT          X( 1)
         IAR           X( 2)


THE INDIVIDUAL GRAPH TITLES AND THE CORRESPONDING VARIABLES

         OUTPUT VS TIME        X( 9) VS. X(10)
          INPUT VS TIME        X( 5) VS. X(10)
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            HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.69


    TIME            VIN             VOUT             IAR

0.25939E 01   0.10927E 03   0.10534E 03   0.77943E 00
0.25955E 01   0.11396E 03   0.10533E 03   0.21453E 01
0.25971E 01   0.10237E 03   0.10532E 03   0.44299E 01
0.25986E 01   0.11499E 03   0.10532E 03   0.61515E 01
0.26002E 01   0.10417E 03   0.10532E 03   0.77398E 01
0.26018E 01   0.11354E 03   0.10532E 03   0.10032E 02
0.26034E 01   0.11017E 03   0.10532E 03   0.11215E 02
0.26050E 01   0.10956E 03   0.10532E 03   0.13665E 02
0.26066E 01   0.11330E 03   0.10532E 03   0.14811E 02
0.26081E 01   0.10344E 03   0.10533E 03   0.16935E 02

0.26097E 01   0.11500E 03   0.10534E 03   0.18412E 02
0.26113E 01   0.94995E 02   0.10535E 03   0.19732E 02
0.26129E 01   0.42135E 02   0.10536E 03   0.13571E 02
0.26145E 01   0.0           0.10535E 03  -0.10000E-01
0.26161E 01   0.11004E 03   0.10534E 03  -0.10000E-01
0.26176E 01   0.11361E 03   0.10533E 03   0.13270E 01
0.26192E 01   0.10398E 03   0.10533E 03   0.37012E 01
0.26208E 01   0.11506E 03   0.10532E 03   0.53498E 01
0.26224E 01   0.10307E 03   0.10532E 03   0.70338E 01
0.26240E 01   0.11392E 03   0.10532E 03   0.92623E 01

0.26256E 01   0.10941E 03   0.10532E 03   0.10487E 02
0.26271E 01   0.11040E 03   0.10532E 03   0.12947E 02
0.26287E 01   0.11341E 03   0.10532E 03   0.14079E 02
0.26303E 01   0.10452E 03   0.10533E 03   0.16286E 02
0.26319E 01   0.11498E 03   0.10534E 03   0.17692E 02
0.26335E 01   0.10256E 03   0.10535E 03   0.19222E 02
0.26351E 01   0.11403E 03   0.10536E 03   0.21209E 02
0.26366E 01   0.85227E 02   0.10537E 03   0.21490E 02
0.26382E 01   0.28545E 02   0.10538E 03   0.13011E 02
0.26398E 01   0.0           0.10537E 03  -0.10000E-01

0.26414E 01   0.0           0.10536E 03  -0.10000E-01
0.26430E 01   0.0           0.10535E 03  -0.10000E-01
0.26446E 01   0.10192E 03   0.10534E 03  -0.10000E-01
0.26461E 01   0.11424E 03   0.10533E 03   0.20354E 01
0.26477E 01   0.10806E 03   0.10533E 03   0.34077E 01
0.26493E 01   0.11109E 03   0.10532E 03   0.59666E 01
0.26509E 01   0.11296E 03   0.10532E 03   0.71914E 01
0.26525E 01   0.10557E 03   0.10532E 03   0.95699E 01
0.26541E 01   0.11490E 03   0.10532E 03   0.11014E 02
0.26556E 01   0.10132E 03   0.10532E 03   0.12750E 02

0.26572E 01   0.11438E 03   0.10532E 03   0.14755E 02
0.26588E 01   0.10617E 03   0.10533E 03   0.15949E 02
0.26604E 01   0.11141E 03   0.10534E 03   0.18296E 02
0.26620E 01   0.11271E 03   0.10535E 03   0.19315E 02
0.26636E 01   0.10606E 03   0.10536E 03   0.21519E 02
0.26651E 01   0.52732E 02   0.10537E 03   0.13558E 02
0.26667E 01   0.0           0.10537E 03   0.45865E 01
0.26683E 01   0.0           0.10536E 03  -0.10000E-01
0.26699E 01   0.0           0.10535E 03  -0.10000E-01
0.26715E 01   0.11172E 03   0.10534E 03   0.40248E 00
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                HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.69


   TIME            VIN              VOUT             IAR


0.26731E 01   0.11245E 03   0.10533E 03   0.16992E 01
0.26746E 01   0.10655E 03   0.10533E 03   0.42117E 01
0.26762E 01   0.11476E 03   0.10532E 03   0.56736E 01
0.26778E 01   0.10009E 03   0.10532E 03   0.75985E 01
0.26794E 01   0.11461E 03   0.10532E 03   0.95853E 01
0.26810E 01   0.10727E 03   0.10532E 03   0.10912E 02
0.26826E 01   0.11202E 03   0.10532E 03   0.13313E 02
0.26841E 01   0.11217E 03   0.10532E 03   0.14408E 02
0.26857E 01   0.10702E 03   0.10533E 03   0.16740E 02
0.26873E 01   0.11467E 03   0.10534E 03   0.17971E 02

0.26889E 01   0.95731E 02   0.10535E 03   0.19751E 02
0.26905E 01   0.50299E 02   0.10536E 03   0.14910E 02
0.26921E 01   0.0           0.10536E 03  -0.10000E-01
0.26936E 01   0.0           0.10535E 03  -0.10000E-01
0.26952E 01   0.11183E 03   0.10534E 03   0.10065E 01
0.26968E 01   0.10748E 03   0.10533E 03   0.35496E 01
0.26984E 01   0.11457E 03   0.10532E 03   0.49639E 01
0.27000E 01   0.10037E 03   0.10532E 03   0.70288E 01
0.27016E 01   0.11460E 03   0.10532E 03   0.89146E 01
0.27031E 01   0.10834E 03   0.10532E 03   0.10309E 02

0.27047E 01   0.11256E 03   0.10532E 03   0.12680E 02
0.27063E 01   0.11155E 03   0.10532E 03   0.13787E 02
0.27079E 01   0.10793E 03   0.10533E 03   0.16162E 02
0.27095E 01   0.11445E 03   0.10534E 03   0.17331E 02
0.27110E 01   0.10030E 03   0.10535E 03   0.19246E 02
0.27126E 01   0.11460E 03   0.10536E 03   0.20681E 02
0.27142E 01   0.91853E 02   0.10537E 03   0.21825E 02
0.27158E 01   0.37117E 02   0.10538E 03   0.14792E 02
0.27174E 01   0.0           0.10538E 03  -0.10000E-01
0.27190E 01   0.0           0.10537E 03  -0.10000E-01

0.27205E 01   0.0           0.10536E 03  -0.10000E-01
0.27221E 01   0.10158E 03   0.10534E 03  -0.10000E-01
0.27237E 01   0.11492E 03   0.10533E 03   0.18498E 01
0.27253E 01   0.10534E 03   0.10533E 03   0.34210E 01
0.27268E 01   0.11306E 03   0.10532E 03   0.58487E 01
0.27284E 01   0.11094E 03   0.10532E 03   0.70754E 01
0.27300E 01   0.10678E 03   0.10532E 03   0.95798E 01
0.27316E 01   0.11417E 03   0.10532E 03   0.10829E 02
0.27332E 01   0.10219E 03   0.10532E 03   0.12927E 02
0.27348E 01   0.11496E 03   0.10532E 03   0.14569E 02

0.27364E 01   0.10432E 03   0.10533E 03   0.15975E 02
0.27380E 01   0.11329E 03   0.10534E 03   0.18172E 02
0.27395E 01   0.11060E 03   0.10535E 03   0.19206E 02
0.27411E 01   0.10919E 03   0.10535E 03   0.21518E 02
0.27427E 01   0.76033E 02   0.10537E 03   0.19635E 02
0.27443E 01   0.65772E 01   0.10536E 03   0.72904E 01
0.27459E 01   0.0           0.10537E 03  -0.10000E-01
0.27475E 01   0.0           0.10536E 03  -0.10000E-01
0.27490E 01   0.0           0.10535E 03  -0.10000E-01
0.27506E 01   0.11025E 03   0.10534E 03   0.74149E 00
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 HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.69


   TIME             VIN              VOUT             IAR


0.27522E 01     0.10958E 03     0.10533E 03     0.33543E 01
0.27538E 01     0.11384E 03     0.10532E 03     0.46677E 01
0.27554E 01     0.10352E 03     0.10532E 03     0.69457E 01
0.27570E 01     0.11590E 03     0.10532E 03     0.85928E 01
0.27585E 01     0.10374E 03     0.10532E 03     0.10174E 02
0.27601E 01     0.11370E 03     0.10532E 03     0.12399E 02
0.27617E 01     0.10987E 03     0.10532E 03     0.13553E 02
0.27633E 01     0.10996E 03     0.10533E 03     0.15965E 02
0.27649E 01     0.11365E 03     0.10533E 03     0.17061E 02
0.27665E 01     0.10388E 03     0.10534E 03     0.19176E 02

0.27680E 01     0.11500E 03     0.10535E 03     0.20582E 02
0.27696E 01     0.95588E 02     0.10537E 03     0.21923E 02
0.27712E 01     0.43082E 02     0.10538E 03     0.15680E 02
0.27728E 01     0.0             0.10536E 03    -0.10000E-01
0.27744E 01     0.0             0.10537E 03    -0.10000E-01
0.27760E 01     0.0             0.10536E 03    -0.10000E-01
0.27775E 01     0.10441E 03     0.10535E 03    -0.10000E-01
0.27791E 01     0.11498E 03     0.10533E 03     0.14336E 01
0.27807E 01     0.10251E 03     0.10533E 03     0.32133E 01
0.27823E 01     0.11406E 03     0.10532E 03     0.54682E 01

0.27839E 01     0.10969E 03     0.10532E 03     0.67659E 01
0.27855E 01     0.11068E 03     0.10532E 03     0.92816E 01
0.27870E 01     0.11322E 03     0.10532E 03     0.10464E 02
0.27886E 01     0.10494E 03     0.10532E 03     0.12755E 02
0.27902E 01     0.11455E 03     0.10532E 03     0.14169E 02
0.27918E 01     0.10203E 03     0.10533E 03     0.15813E 02
0.27934E 01     0.11421E 03     0.10534E 03     0.17823E 02
0.27950E 01     0.10388E 03     0.10535E 03     0.18939E 02
0.27965E 01     0.11102E 03     0.10536E 03     0.21246E 02
0.27981E 01     0.74973E 02     0.10537E 03     0.20062E 02

0.27997E 01     0.12992E 02     0.10533E 03     0.88641E 01
0.28013E 01     0.0             0.10537E 03    -0.10000E-01
0.28029E 01     0.0             0.10536E 03    -0.10000E-01
0.28045E 01     0.0             0.10535E 03    -0.10000E-01
0.28060E 01     0.10825E 03     0.10534E 03     0.65567E 00
0.28076E 01     0.11135E 03     0.10533E 03     0.34463E 01
0.28092E 01     0.11276E 03     0.10532E 03     0.47047E 01
0.28108E 01     0.10597E 03     0.10532E 03     0.71431E 01
0.28124E 01     0.11485E 03     0.10532E 03     0.85988E 01
0.28140E 01     0.10082E 03     0.10532E 03     0.10414E 02

0.28155E 01     0.11448E 03     0.10532E 03     0.12418E 02
0.28171E 01     0.10782E 03     0.10532E 03     0.13668E 02
0.28187E 01     0.11165E 03     0.10533E 03     0.16043E 02
0.28203E 01     0.11251E 03     0.10533E 03     0.17095E 02
0.28219E 01     0.10645E 03     0.10534E 03     0.19356E 02
0.28234E 01     0.63584E 02     0.10535E 03     0.16570E 02
0.28250E 01     0.0             0.10535E 03     0.28069E 01
0.28266E 01     0.11459E 03     0.10534E 03     0.33695E 00
0.28282E 01     0.10737E 03     0.10534E 03     0.18011E 01
0.28298E 01     0.11196E 03     0.10533E 03     0.43479E 01
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                         HASAN KOCAOGLU.SPEED CONTROL OF A DC.MOTOR.NO.69


    TIME           VIN            VOUT           IAR


0.28314E 01    0.11223E 03    0.10532E 03    0.55844E 01
0.28329E 01    0.10693E 03    0.10532E 03    0.60535E 01
0.28345E 01    0.11469E 03    0.10532E 03    0.94322E 01
0.28361E 01    0.99519E 02    0.10532E 03    0.11341E 02
0.28377E 01    0.11469E 03    0.10532E 03    0.13225E 02
0.28393E 01    0.10890E 03    0.10533E 03    0.14514E 02
0.28409E 01    0.11224E 03    0.10533E 03    0.16841E 02
0.28424E 01    0.11194E 03    0.10534E 03    0.17677E 02
0.28440E 01    0.10739E 03    0.10535E 03    0.20164E 02
0.28456E 01    0.55718E 02    0.10536E 03    0.17676E 02

0.28472E 01    0.13061E 01    0.10537E 03    0.43735E 01
0.28488E 01    0.0            0.10536E 03   -0.10000E-01
0.28504E 01    0.10643E 03    0.10535E 03   -0.10000E-01
0.28519E 01    0.11251E 03    0.10534E 03    0.24786E 01
0.28535E 01    0.11165E 03    0.10533E 03    0.37448E 01
0.28551E 01    0.10784E 03    0.10532E 03    0.52760E 01
0.28567E 01    0.11447E 03    0.10532E 03    0.76278E 01
0.28583E 01    0.10086E 03    0.10532E 03    0.96719E 01
0.28599E 01    0.11465E 03    0.10532E 03    0.11475E 02
0.28614E 01    0.10544E 03    0.10532E 03    0.12855E 02

0.28630E 01    0.11277E 03    0.10533E 03    0.15164E 02
0.28646E 01    0.11133E 03    0.10533E 03    0.16233E 02
0.28662E 01    0.10626E 03    0.10534E 03    0.18577E 02
0.28678E 01    0.11434E 03    0.10535E 03    0.19706E 02
0.28694E 01    0.10140E 03    0.10537E 03    0.21599E 02
0.28709E 01    0.53511E 02    0.10538E 03    0.17231E 02
0.28725E 01    0.0            0.10538E 03    0.14685E 01
0.28741E 01    0.0            0.10537E 03   -0.10000E-01
0.28757E 01    0.0            0.10536E 03   -0.10000E-01
0.28773E 01    0.10870E 03    0.10535E 03   -0.10000E-01

0.28789E 01    0.11426E 03    0.10534E 03    0.13694E 01
0.28804E 01    0.10205E 03    0.10533E 03    0.36053E 01
0.28820E 01    [illegible]    0.10532E 03    0.54022E 01
0.28836E 01    0.10492E 03    0.10532E 03    0.69475E 01
0.28852E 01    0.11324E 03    0.10532E 03    0.92969E 01
0.28868E 01    0.11067E 03    0.10532E 03    0.10477E 02
0.28884E 01    0.10911E 03    0.10532E 03    0.12933E 02
0.28899E 01    0.11404E 03    0.10532E 03    0.14115E 02
0.28915E 01    0.10255E 03    0.10533E 03    0.16193E 02
0.28931E 01    0.11495E 03    0.10534E 03    0.17745E 02

0.28947E 01    0.10439E 03    0.10535E 03    0.19128E 02
0.28963E 01    0.11346E 03    0.10535E 03    0.21246E 02
0.28979E 01    0.83284E 02    0.10537E 03    0.21160E 02
0.28994E 01    0.24334E 02    0.10538E 03    0.11954E 02
0.29010E 01    0.0            0.10537E 03   -0.10000E-01
0.29026E 01    0.0            0.10536E 03   -0.10000E-01
0.29042E 01    0.0            0.10535E 03   -0.10000E-01
0.29058E 01    0.10384E 03    0.10534E 03    0.87598E-01
0.29074E 01    0.11366E 03    0.10533E 03    0.24754E 01
0.29089E 01    0.10994E 03    0.10533E 03    0.37830E 01
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     TIME             VIN              VOUT             IAR


 0.29105E 01   0.10969E 03   0.10532E 03   0.63506E 01
 0.29121E 01   0.11369E 03   0.10532E 03   0.76041E 01
 0.29137E 01   0.10375E 03   0.10532E 03   0.98664E 01
 0.29153E 01   0.11500E 03   0.10532E 03   0.11433E 02
 0.29169E 01   0.10329E 03   0.10532E 03   0.13004E 02
 0.29184E 01   0.11385E 03   0.10533E 03   0.15152E 02
 0.29200E 01   0.10557E 03   0.10533E 03   0.16274E 02
 0.29216E 01   0.11025E 03   0.10534E 03   0.18640E 02
 0.29232E 01   0.11349E 03   0.10535E 03   0.19681E 02
 0.29248E 01   0.10431E 03   0.10535E 03   0.21779E 02

 0.29264E 01   0.59035E 02   0.10536E 03   0.18270E 02
 0.29279E 01   0.0           0.10538E 03   0.35320E 01
 0.29295E 01   0.0           0.10537E 03  -0.10000E-01
 0.29311E 01   0.0           0.10536E 03  -0.10000E-01
 0.29327E 01   0.0           0.10535E 03  -0.10000E-01
 0.29343E 01   0.11328E 03   0.10534E 03   0.97115E 00
 0.29358E 01   0.10484E 03   0.10533E 03   0.34043E 01
 0.29374E 01   0.11450E 03   0.10532E 03   0.49945E 01
 0.29390E 01   0.10213E 03   0.10532E 03   0.67557E 01
 0.29406E 01   0.11418E 03   0.10532E 03   0.89212E 01

 0.29422E 01   0.10376E 03   0.10532E 03   0.10179E 02
 0.29438E 01   0.11095E 03   0.10532E 03   0.12635E 02
 0.29453E 01   0.11300E 03   0.10532E 03   0.13756E 02
 0.29469E 01   0.10533E 03   0.10533E 03   0.16017E 02
 0.29485E 01   0.11102E 03   0.10533E 03   0.17369E 02
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13. ABSTRACT

The concept of a limit cycling control in power supplies and speed control has advanced the application of these broad areas. ON-OFF switching of a thyristor provides a simple and economical method of control and regulation. This switching of the thyristor causes the system to limit cycle.

Basic analysis and design of speed control was performed. A describing function was developed to model the power-supply and rectifier bridge. Then it was used to predict the frequency and amplitude of the limit cycle.

A digital computer program was used to simulate the system response and to construct the describing function curves. To verify the describing function validity, the limit cycle predictions were compared with the simulated results.

Fourier analyses were performed to determine the ripple instability and subharmonic effect of the system output.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Limit-cycle						
Thyristor						
Describing-function						
Ripple instability						
Subharmonics						

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